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Industrial Hygiene

ASSOCIATION

Journal

VOLUME 22, NUMBER 3

JUNE 1961

From Preliminary Sound-Level Measurements..

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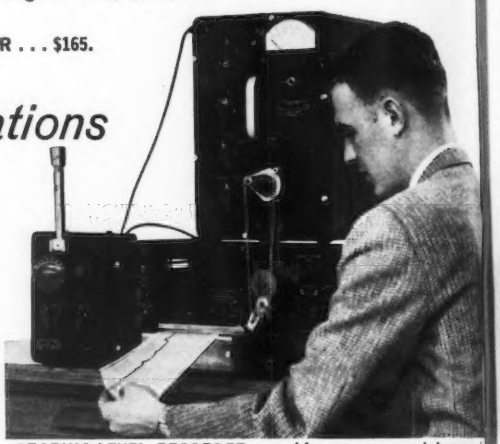

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a versatile instrument that provides detailed information concerning the distribution of noise and vibration components over the frequency range from 2.5 to 25,000 cps. Three modes of operation: *Narrow Band*, for measurement of single-frequency components — *One-Third-Octave Band*, for analysis of broad-band spectra — *All-Pass*, for convenient evaluation of overall level to 25 kc.

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CUMMINGS MEMORIAL AWARD

The 1961 Cummings Memorial Award was given posthumously to Manfred Bowditch at the annual banquet of the American Industrial Hygiene Association at Detroit, Michigan, April 12, 1961. His wife, Mrs. Elfriede Bowditch, was unable to attend and asked that their longtime friend, Dr. Thomas L. Shipman, accept the award for them. In keeping with the honor intended and carried by this award, it is most appropriate that we present here Dr. Shipman's remarks on acceptance of the award on behalf of Mrs. Bowditch.

Words do not come easily for me on this occasion. I confess, however, that when Elfriede Bowditch asked me to accept in her name this award to Manfred, I agreed without hesitation because it would give me an opportunity to express in some slight measure the feelings of admiration and affection which I hold for them both. The fact that Manfred's name now joins a list of illustrious predecessors indicates that my admiration for him was shared by the rest of you, so I feel that I am speaking not for myself but for you all. As for affection, I know of few men who have had more friends. It is entirely fitting and in no way surprising that Don Cummings himself was one of the closest.

There were many sides to Manfred's character, all of them admirable and endearing, and almost any one of them could be described at length. He was a Proper Bostonian, a Brahmin in good standing. As a matter of fact, he could never be mistaken for anything *but* a Bostonian and a Harvard graduate, no matter where you might encounter him. Just as the sailing vessels from Salem in the days of Manfred's great-great grandfather, Nathaniel, could be recognized by the cut of their jibs, so can a Proper Bostonian today be recognized by the cut and angle of his hat.

There are many characteristics commonly attributed to Proper Bostonians which were quite foreign to Manfred. He was a true liberal, never quite satisfied with the state of the world around him. It was that very dissatisfaction that made him a pioneer and a crusader. He had an understandable lack of patience with ineptitude and mediocrity in any form, and this sometimes led to explosions of temper which were the secret joy of his many friends, because he was usually expressing just what they wanted to say but did not dare. He was an idealist with an unbending code of moral and ethical values.

But Manfred at the same time had a sense of humor and love of the ridiculous that was a part of his great capacity for friendliness. His friends came from all walks of life—he and Elfriede were at their most sparkling when entertaining a group whether it was at Marlboro Street in Boston, at Saranac, at East Ninth Street, or in a hotel room. One thing characterized their wide circle of friends—they were never dull. In Manfred's presence a guest had little opportunity to be dull as he could find an area of common interest in almost everyone.

Among the great figures in the world of Industrial Hygiene Manfred was something of an anachronism. He was not a chemist or an engineer or a toxicologist nor did he ever try to pass as one of these or become one. He was responsible as much as any one person, however, for seeing and establishing the need for these specialties, and he had the enjoyment of watching this vacuum rapidly fill. Manfred Bowditch in 1925 was probably the first industrial hygienist to be employed full-time by any industry in the country. In those very early days he concerned himself with ventilation, primarily to remove excessive heat, with lighting to prevent eyestrain, with posture and the provision of proper chairs to reduce muscular strain.

It was our beloved Alice Hamilton who showed Manfred that the field was far wider than he realized, and in 1934 he drafted the legislation that established the Massachusetts Division of Occupational Hygiene. Manfred, Leonard Greenburg and Albert Gray sort of grew up together along with their respective divisions in Massachusetts, New York and Connecticut, the first such organizations to continue without interruption to the present.

As director of the division Manfred went through a series of major interests—silicosis, asbestosis, benzol poisoning, radium poisoning, beryllium poisoning; but perhaps his major preoccupation was in developing young men with a competence for and a dedication to the field of industrial health. Bowditch alumni are now spread across the country in positions of responsibility and leadership.

In 1946 Manfred went to the Saranac Labora-

tory to join Roy Gardner, and in 1948 he moved to New York to assume the position with the Lead Industries Association which he held until his death last summer. He was the only person to serve two terms as a Director of the AIHA and he was the work horse on innumerable committees both in this and in other organizations. People always enjoyed being on a committee with Manfred, knowing full well that he would do most of the work. No one ever gave more of himself to his work and we will never have a more dedicated member.

We are proud that the AIHA has recognized and honored Manfred Bowditch, saddened that he could not receive the award into his hands. Speaking for Elfriede Bowditch, I thank you all.

Honorary Membership

DR. W. F. VON OETTINGEN (right) is shown accepting the certificate of honorary membership in the American Industrial Hygiene Association. This honor was bestowed upon Dr. von Oettingen in recognition of his many years of outstanding service to the field and the profession. The presentation is made by Mr. Jack C. Radcliffe, now Past-President of the American Industrial Hygiene Association.

Ten Years' Experience with Industrial Audiometry

E. C. RILEY, M.D., J. H. STERNER, M.D., D. W. FASSETT, M.D., and W. L. SUTTON, M.D.

Laboratory of Industrial Medicine, Eastman Kodak Company, Rochester, New York

Data from audiograms of 2789 males and 2875 females are presented and discussed to demonstrate age and sex as factors in hearing levels. The test groups were selected to minimize possibilities of disease or prior noise exposures affecting the results. Agreement with reports of other observers is excellent. A significant difference in hearing of men and women is found. Data establish a reasonably reliable norm for presbycusis.

PURE tone audiometry was first used by Eastman Kodak Company in 1950 to screen applicants for employment. The procedure employed a sweep-check technique in which the signal attenuator was set at a pre-determined level (in this case 15 db) and the applicant was asked to indicate whether or not he heard the signal at each of the several frequencies "swept by the frequency selector." If the person failed to hear the signal at more than one frequency, a complete pure-tone threshold examination was carried out.

A review of the literature and consultation with recognized authorities soon revealed a serious lack of agreement with respect to the effect of noise on hearing.[1] It was apparent that much more information relating industrial noise exposure to hearing loss was needed.

It was recognized that an essential element in the collection of reliable information was the standardization of audiometric testing technique. Since with slightly more time and effort, a complete pure-tone threshold audiogram could be obtained on each examination, the sweep check screening technique was discarded in favor of the complete audiogram. This not only provided a more adequate medical-legal reference, but also supplied quantitative information concerning pure-tone hearing thresholds. Experience with the pure-tone threshold audiogram led to questions concerning the variables in this technique. Experiments were then designed to determine both the magnitude of the inherent variables which could not be controlled, and the existence and magnitude of controllable variables. Many field observations were needed. In addition, sophisticated statistical techniques were required to evaluate the many variables which could, and did, affect the data. When more than one audiometer, technician, and testing area or booth are used in this type of program, it becomes important to evaluate and, if possible, to control any differences which may be present, as well as any changes which may occur with time. There are also differences between operators and operator repeatability which should be determined, as well as possible interactions between any of these factors and the subjects being tested.

Although a complete description of the studies which were carried out to demonstrate these differences is not possible in this report, it may be worthwhile to indicate the results of some of these studies.[2]

The first and perhaps most important physical factor is the environment in which the test is made. Our experience, as well as that of others, indicates that if accurate air conduction threshold audiograms are to be obtained on normal young adults in an industrial setting, an adequate audiometric test booth is required.

Secondly, although commercial audiometers currently on the market are generally within the ASA standards for audiometers for most frequencies, the variability among audiometers and in any given audiometer with time is considerable, particularly in the frequencies 4,000 and above. For this reason, the audiometric technician should make daily tests of his own threshold as a rough check of the audiometer; and there should be periodic, at least yearly, electrical and physical calibration of the instrument.

In addition to the strictly physical variables, it is important to reduce the differences in audiometric testing procedures and techniques

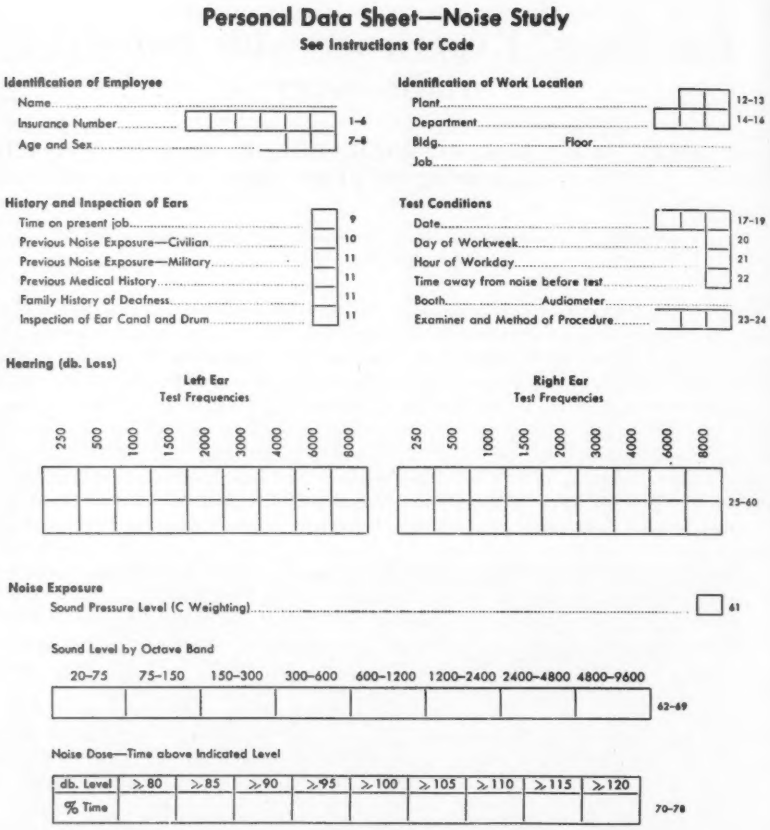
Personal Data Sheet—Noise Study
See Instructions for Code
Identification of Employee
Name
Insurance Number 1–6
Age and Sex 7–8
Identification of Work Location
Plant 12–13
Department 14–16
Bldg. Floor
Job
History and Inspection of Ears
Time on present job 9
Previous Noise Exposure—Civilian 10
Previous Noise Exposure—Military 11
Previous Medical History 11
Family History of Deafness 11
Inspection of Ear Canal and Drum 11
Test Conditions
Date 17–19
Day of Workweek 20
Hour of Workday 21
Time away from noise before test 22
Booth Audiometer
Examiner and Method of Procedure 23–24
Hearing (db. Loss)
Left Ear
Test Frequencies
Right Ear
Test Frequencies
250 500 1000 1500 2000 3000 4000 6000 8000
250 500 1000 1500 2000 3000 4000 6000 8000
25–60
Noise Exposure
Sound Pressure Level (C Weighting) 61
Sound Level by Octave Band
20–75 75–150 150–300 300–600 600–1200 1200–2400 2400–4800 4800–9600
62–69
Noise Dose—Time above Indicated Level
db. Level ≥ 80 ≥ 85 ≥ 90 ≥ 95 ≥ 100 ≥ 105 ≥ 110 ≥ 115 ≥ 120
% Time
70–78

FIGURE 1.

through a personnel training program. As an aid in the recording of complete and consistent data, a well designed form or data sheet can be most useful. Figure 1 shows a form which we have designated "Personal Data Sheet-Noise Study", which contains necessary information from the employee's past history and present environment in addition to the hearing threshold. This record is designed so that the information can be transferred to an 80-column IBM punch card to facilitate statistical analysis of group data. The information includes the identity and vital statistics of the employee: insurance number, age and sex, followed by history and inspection of ears. Identification of work location includes the plant, department, building, floor and individual's job. Also recorded are such items as the date, day of the work week, hours of the work day, time away from noise before test, the booth, audiometer, examiner, and audiometric procedure. The last entry by the audiometric technician is the hearing threshold recorded in decibels.

The final section contains pertinent information about the individual's exposure. The overall sound pressure level is routinely included, when available, from a previous or concurrent sound survey. Sound level by octave bands and the so-called "noise dose", which is a time-intensity factor, are not generally available for the individual employee.

To obtain uniformity and completeness, this form is used throughout all our plants and is filled out for *every* audiometric test regardless of the purpose for which the test is made. The form itself does not appear in the medical record, but the hearing threshold is recorded. In addition, all of the data from these forms are transferred to punch cards and are available for periodic summarization and analysis. This

form has been essentially unchanged since its introduction in 1955 and 17,549 punch cards, obtained through the use of this form, were studied in preparing this review.

When the study of individuals and groups of people in relation to hearing acuity was started, the lack of established criteria with respect to age and sex made it difficult to interpret the significance of the findings. In reviewing ten years' experience with industrial audiometry, it seemed desirable to study the magnitude and variability of the normal hearing threshold for men and for women and the effect of aging on this threshold. This information was needed as background for the interpretation of group data.

In reviewing our data to develop the effect of age on hearing, it was difficult to decide what to include and what to discard. The group was selected for the following attributes indicated on the personal data sheets: (1) no history of previous noise exposure (military or civilian), (2) negative previous medical history of disease involving the ear or hearing mechanism, (3) no family history of deafness, and (4) no indication of abnormality on inspection of the external canal and drum. In the group, as qualified above, there were three classes of individuals: (1) applicants for employment, (2) employed persons lacking actual noise measurements but with a negative history of noise exposure, and (3) those working in environments with an observed sound pressure level of less than 80 db overall.

After these groups were selected, the cards were resorted and any repeat examinations discarded. The final study group consisted of 5,664 individuals (2,789 males and 2,875 females) without evidence of ear disease or noise exposure selected from 17,549 audiometric examinations. These were separated into five decades from 16 to 65 years of age and two sexes, giving 10 basic groups. For each individual, nine frequencies were tested for each ear for a total of 18 threshold measurements. For each frequency and each ear, group means and standard de-

TABLE I

Hearing Thresholds* by Age Groups for Males in the Selected Normal Population

Test Frequency cps	Ear	16–25 Years N = 1291		26–35 Years N = 526		36–45 Years N = 417		46–55 Years N = 367		56–65 Years N = 188	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
250	R	−4.69	6.7	−4.90	6.3	−4.18	7.6	−2.86	8.6	0.00	9.1
	L	−3.52	7.7	−3.49	7.4	−3.14	8.5	−0.77	11.1	0.45	10.9
	Both	−4.19	6.3	−4.27	6.1	−3.74	7.3	−1.82	8.9	0.24	9.1
500	R	−3.55	6.6	−3.72	6.4	−2.61	8.1	−0.80	8.8	2.93	9.6
	L	−3.32	6.2	−2.93	6.1	−2.15	9.0	0.65	10.7	3.35	11.0
	Both	−3.53	5.8	−3.41	6.0	−2.43	7.7	−0.07	9.1	3.14	9.4
1000	R	−3.59	6.6	−2.53	7.1	−1.57	8.6	1.01	9.1	5.51	12.2
	L	−3.95	6.0	−2.73	6.6	−0.91	9.4	1.89	9.7	5.88	12.6
	Both	−3.88	5.8	−2.70	6.4	−1.27	8.2	1.47	8.6	5.76	11.4
1500	R	−3.90	6.7	−2.39	7.7	−0.80	10.0	2.64	11.0	9.12	14.1
	L	−3.81	6.8	−2.40	8.3	−0.32	10.6	3.34	12.2	10.35	16.1
	Both	−3.98	6.7	−2.47	7.4	−0.63	9.4	3.00	10.7	9.81	13.9
2000	R	−2.35	7.4	−0.50	8.9	2.11	12.3	5.46	13.1	13.51	16.4
	L	−1.32	7.8	0.36	9.6	3.50	12.1	8.27	14.2	16.57	18.6
	Both	−1.91	6.9	−0.11	8.5	2.82	11.1	6.95	12.8	15.18	16.2
3000	R	−2.21	9.1	2.80	13.5	7.29	16.4	13.01	18.1	26.14	21.4
	L	−1.33	10.0	3.65	13.6	9.72	16.7	17.93	19.4	27.82	21.1
	Both	−1.84	8.7	3.23	12.5	8.60	15.3	15.63	17.4	27.19	19.8
4000	R	4.05	12.7	12.24	16.8	17.53	19.4	24.1	18.4	38.96	22.2
	L	5.63	13.3	13.44	16.8	18.82	18.8	28.35	19.5	41.30	20.4
	Both	4.90	11.9	12.98	15.2	18.35	17.8	26.44	17.5	40.35	19.5
6000	R	4.36	14.0	12.13	17.9	19.00	19.4	24.03	19.0	39.78	22.5
	L	5.47	13.8	12.53	17.0	18.78	18.6	27.77	19.0	42.88	20.6
	Both	4.96	12.6	12.48	15.7	19.10	17.3	26.12	17.3	41.56	20.1

* Expressed in decibels.

viations were computed. Then the thresholds for left and right ears were averaged and a mean and standard deviation computed for each frequency. These data are presented in Tables I and II.

The mean of the average of left and right ears and standard deviation about this mean have been plotted for each frequency. Figure 2 shows these means plus or minus 1 standard deviation for each sex and age group. Since the audiometer measures only to −10 db, the threshold values for young healthy ears are not normally distributed about the mean. For this reason the mean and standard deviation do not completely describe the distribution. However, these measures have been used in many other audiometric studies and, therefore, serve as useful parameters. In general, these curves show that there is a progressive loss of hearing acuity with age, greater in the male than in the female and more pronounced in the higher frequencies. The standard deviation tends to be minimal at 1,000 cps and increases markedly at the higher frequencies and in the older age groups.

By plotting the data somewhat differently, using age as the abscissa, it may be easier to visualize the effect of age on the hearing threshold for the various frequencies. Table III shows the hearing thresholds for men and women relative to the threshold for the 20-year old subjects in the screened normal group. This information is shown graphically in Figure 3. Again it is apparent that there is a progressive loss of acuity with age and that this is more pronounced in the higher frequencies, and greater in the male. The number in each group, with the exception of the older females, was well over 100 and for the younger ages, well over 1,000. The size of the samples makes it unlikely that the means or standard deviations will change appreciably as additional observations are obtained.

These studies include data from examinations made in Kingsport, Tennessee as well as in

TABLE II

Hearing Thresholds* by Age Groups for Females in the Selected Normal Population

Test Frequency cps	Ear	16–25 Years N = 1974		26–35 Years N = 463		36–45 Years N = 302		46–55 Years N = 99		56–65 Years N = 37	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
250	R	−5.43	6.4	−4.10	7.1	−2.33	8.7	−1.36	8.0	1.22	11.4
	L	−4.42	7.4	−3.29	8.2	−0.71	10.1	1.31	11.7	3.65	13.5
	Both	−5.02	5.9	−3.77	6.9	−1.56	8.6	−0.05	8.2	2.49	11.8
500	R	−4.65	5.9	−3.38	7.4	−1.03	9.0	0.50	8.4	4.46	13.8
	L	−4.71	6.0	−3.41	7.2	−1.01	9.3	0.96	10.4	4.86	13.4
	Both	−4.80	5.2	−3.52	6.8	−1.02	8.6	0.48	8.1	4.81	13.2
1000	R	−4.70	5.7	−3.23	6.8	−1.27	7.5	−0.05	7.0	4.86	15.3
	L	−5.41	5.4	−4.02	7.8	−1.62	8.6	−0.20	9.7	4.73	15.4
	Both	−5.20	4.7	−3.74	6.4	−1.53	7.4	−0.18	7.0	4.78	15.2
1500	R	−4.51	6.2	−3.53	6.4	−1.80	7.8	0.20	8.1	6.62	15.9
	L	−5.25	5.9	−3.62	7.4	−1.72	8.5	0.51	9.5	7.84	18.0
	Both	−5.02	5.2	−3.70	6.1	−1.90	7.2	0.30	7.7	7.30	16.6
2000	R	−2.90	6.8	−2.25	7.0	0.75	8.8	3.03	8.7	10.54	15.1
	L	−3.31	6.5	−1.63	8.2	0.51	8.3	3.28	9.4	11.22	16.1
	Both	−3.21	5.8	−2.01	6.8	0.62	7.9	3.15	8.0	11.03	15.1
3000	R	−5.09	6.3	−3.67	6.9	−0.02	8.8	3.94	9.6	11.49	17.1
	L	−5.33	6.1	−2.79	8.9	0.96	10.3	4.23	11.4	13.65	16.8
	Both	−5.34	5.3	−3.32	7.1	0.47	8.7	4.16	9.2	12.73	16.3
4000	R	−0.24	8.8	2.53	9.7	6.27	11.4	11.52	13.4	17.70	18.2
	L	−0.38	8.4	3.17	11.2	7.90	12.2	11.82	11.8	21.89	18.6
	Both	−0.33	7.4	2.92	9.1	7.22	10.3	11.87	11.0	20.08	17.4
6000	R	−0.81	8.8	2.24	10.3	7.24	13.3	13.18	13.9	23.38	17.9
	L	−1.25	8.6	2.31	10.9	8.41	13.4	13.08	13.2	22.57	16.8
	Both	−1.07	7.5	2.31	9.4	7.96	12.0	13.26	11.9	23.19	16.8

* Expressed in decibels.

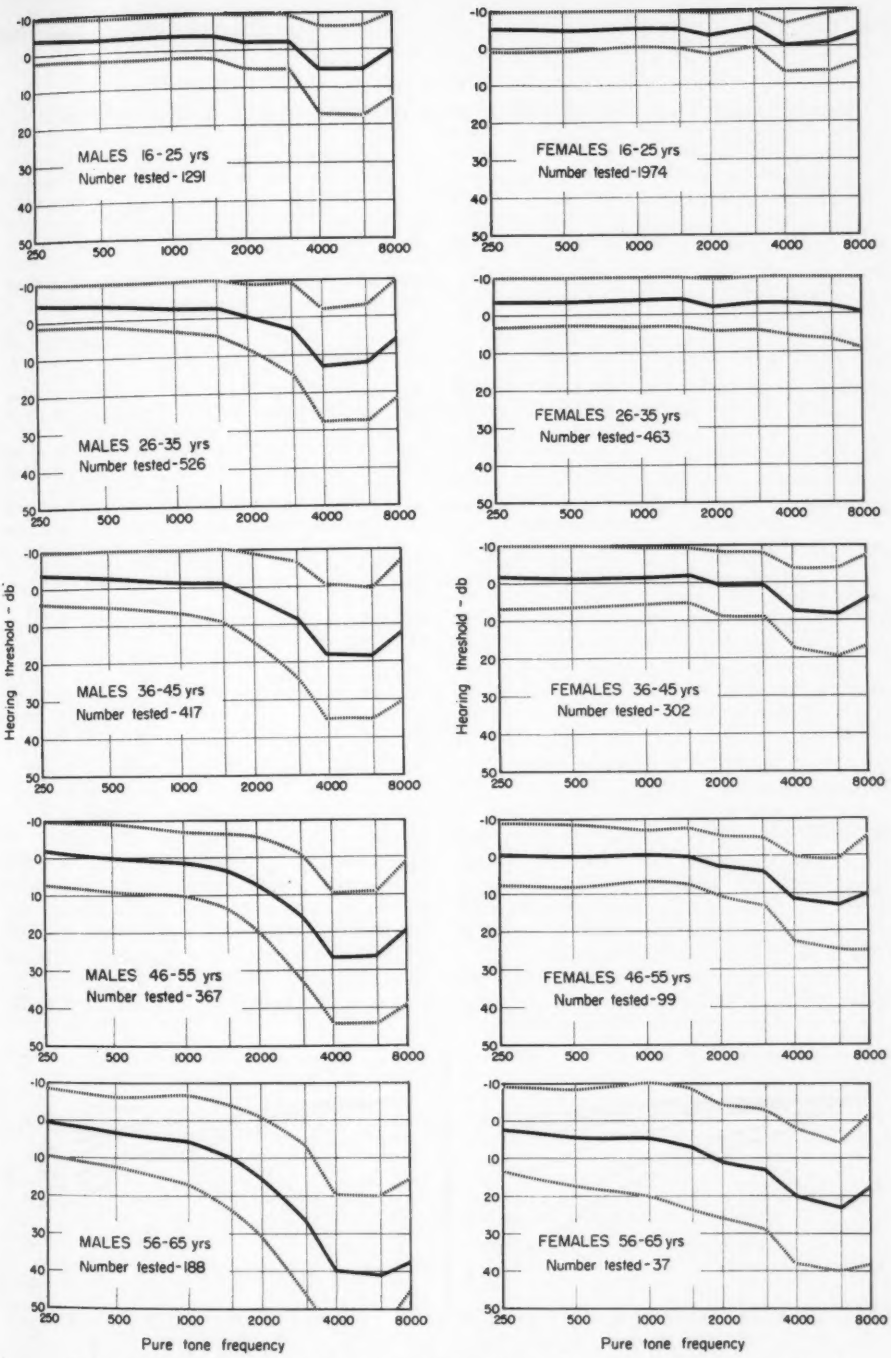

FIGURE 2. Hearing thresholds by age grouping and sex. The mean average hearing threshold in db of left and right ears have been plotted (solid line) against pure tone frequency. The broken lines show plots of plus one and minus one standard deviation.

TABLE III

Hearing Threshold* by Age and Sex Referred to the Threshold of the 16–25 Year Group as 0

Test Frequency cps	Sex	Age														
		16–25 Years			26–35 Yrs.			36–45 Yrs.			46–55 Yrs.			56–65 Yrs.		
		Mean	S.D.	N.	Mean	S.D.	N.	Mean	S.D.	N.	Mean	S.D.	N.	Mean	S.D.	N.
250	M	0	6.3	1291	0	6.1	526	0.5	7.4	417	2.4	8.9	367	4.4	9.1	188
	F	0	6.4	1974	1.2	6.9	463	3.5	8.6	302	6.3	8.2	99	7.5	11.8	37
500	M	0	5.8	1291	0	6.0	526	1.0	7.7	417	3.6	9.1	367	6.6	9.4	188
	F	0	5.9	1974	1.3	6.8	463	3.8	8.6	302	5.8	8.2	99	9.6	13.2	37
1000	M	0	5.8	1291	1.0	6.4	526	2.6	8.2	417	5.3	8.6	367	9.6	11.4	188
	F	0	5.7	1974	1.5	6.4	463	3.7	7.4	302	5.0	7.1	99	10.0	15.3	37
1500	M	0	6.1	1291	1.5	7.4	526	3.4	9.4	417	7.0	10.8	367	13.8	13.9	188
	F	0	6.2	1974	1.3	6.1	463	3.1	7.2	302	5.5	7.7	99	12.3	16.6	37
2000	M	0	6.9	1291	1.8	8.5	526	4.7	11.1	417	8.9	12.8	367	17.1	16.2	188
	F	0	6.8	1974	1.2	6.8	463	3.8	8.0	302	6.5	8.1	99	14.2	15.1	38
3000	M	0	8.7	1291	5.0	12.5	526	10.4	15.3	417	17.5	17.5	367	29.0	19.9	188
	F	0	5.3	1974	2.0	7.1	463	5.8	8.7	302	9.6	9.2	99	18.1	16.3	37
4000	M	0	11.9	1291	8.0	15.3	526	13.4	17.8	417	21.5	17.6	367	35.5	19.6	188
	F	0	8.8	1974	3.2	9.1	463	7.5	10.3	302	12.2	11.1	99	20.4	17.8	37
6000	M	0	12.3	1291	7.5	15.8	526	14.0	17.4	417	21.1	17.4	367	36.6	20.2	188
	F	0	8.8	1974	3.4	9.4	463	9.0	12.0	302	14.2	11.9	99	24.3	16.9	37
8000	M	0	11.9	1291	5.8	15.7	526	12.4	18.8	417	19.6	19.2	367	37.6	22.0	188
	F	0	9.0	1974	3.1	9.7	463	7.4	12.8	302	14.4	15.3	99	21.6	20.1	37

* Expressed in decibels.

Rochester, New York. Before grouping the data, it was determined that there was no significant difference between properly screened groups from the various plants and geographic areas. This suggests that our techniques, as well as the study populations, are similar.

In addition to presenting the results from our studies of selected groups of Kodak employees and applicants for employment, we have compared our results with those of others who have studied this problem. One of the bases for comparison is the presbycusis curves published in the 1954 ASA report "The Relations of Hearing Loss to Noise Exposure".[3] Another important study, published in *Acustica* in 1959,[4] is that of R. Hinchcliffe from the Medical Re-

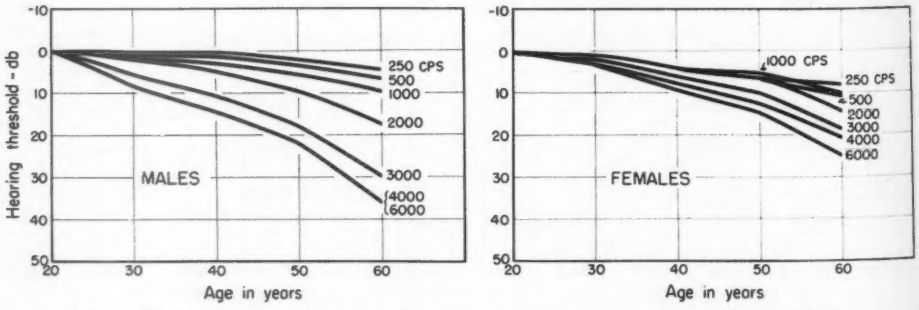

FIGURE 3. Hearing thresholds for males and females relative to the threshold for 20-year old subjects in the screened normal group.

TABLE IV

Comparison of E. K. Co. Data with Other Presbycusis Studies*

(Threshold for 20 year old subjects = 0)

Age Group	1000 cps			4000 cps		
	ASA	E. K. Co.	Hinch-cliffe	ASA	E. K. Co.	Hinch-cliffe
	Mean		Median	Mean		Median
Males						
20	0	0	0	0	0	0
30	0	1.0	1.0	3.5	8.0	4.0
40	1.5	2.6	1.7	11.5	13.4	9.1
50	4.5	5.3	4.7	21.0	21.5	18.7
60	8.0	9.6	5.6	31.5	35.5	34.3
Females						
20	0	0	0	0	0	0
30	1.5	1.5	1.0	1.5	3.2	3.8
40	4.0	3.7	1.7	5.0	7.5	5.3
50	7.0	5.0	4.7	12.0	12.2	13.2
60	9.5	10.0	5.6	17.0	20.4	19.4

* Thresholds in decibels.

search Council, Wernher Unit on Deafness, London. His investigation was carefully controlled in an attempt to determine "the threshold of hearing as a function of age". In his summary he states "the threshold of hearing has been measured ... on a random sample stratified by age and sex that had been drawn from a representative rural population in Great Britain. Clinically abnormal ears were discarded from the analysis." Although he used quartiles for his parameter, the median value from his studies corresponds closely to the mean which has been applied in our studies.

Table IV and Figure 4 show the comparison for the various age groups for the frequencies 1,000 and 4,000 cps. The squares indicate points taken from the presbycusis curves for men and for women shown in the report of the American Standards Association Subcommittee Z24-X-2. The ASA study included data from normal ears from Baltimore, Maryland, the New York Worlds Fair, and the San Diego County Fair. In addition, the medians determined by R. Hinchcliffe (triangles) from a carefully screened rural population in Great Britain are plotted. The Eastman Kodak data (circles) was obtained in Rochester, New York and Kingsport, Tennessee. There is remarkable agreement among the data obtained from these varied sources.

The same general agreement can be seen when the data are plotted in another way as shown in Figure 5 and presented in Table V. In these figures the same data are compared for all frequencies in two selected age groups. The Kodak 40-year old group (36–45) and the nearest comparable group from Hinchcliffe's data (35–44 years) are shown with values taken from the ASA curves. In a similar manner, the data for the 60-year old group from the three studies have been plotted. Again the agreement is surprisingly good, not only at 1,000 and 4,000 cps, but for the entire range of frequencies tested in these studies. Although similar data for other ages and frequencies are not presented, the agreement in results is excellent.

From these data, the following summary and conclusions seem justified:

1. The effect of age on the air conduction threshold for hearing has been determined for a large population, from which individuals with a history of ear disease and significant noise exposure have been removed.

2. The data give a reasonably accurate portrayal of the mean and variability of hearing

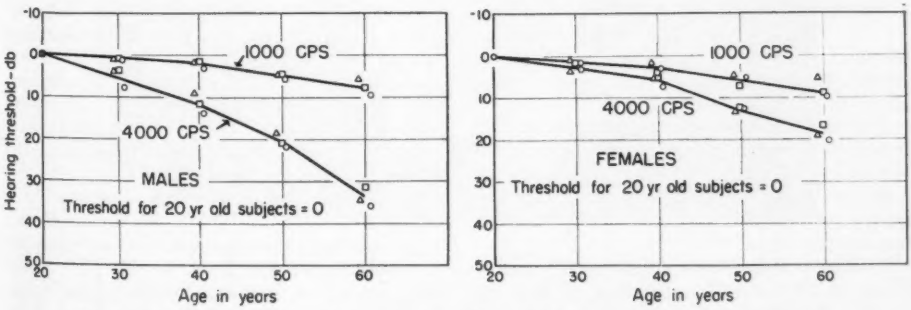

FIGURE 4. Comparison of various age groups for the frequencies 1,000 and 4,000 cps.

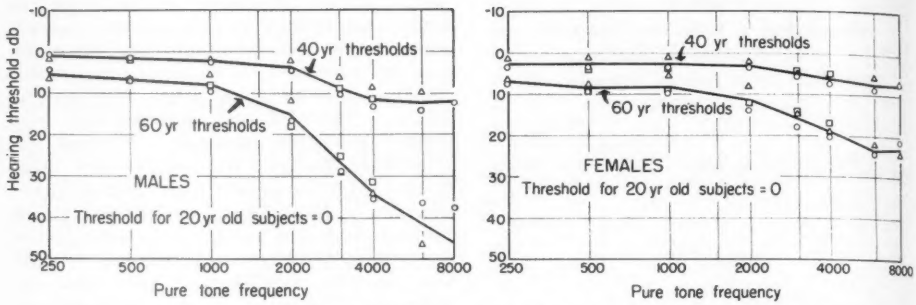

FIGURE 5. Comparison of thresholds for two selected age groups of males and females at all frequencies against thresholds of 20 year old subjects.

TABLE V

Comparison of E. K. Co. Data with Other Presbycusis Studies*

(Threshold for 20 year old subjects = 0)

Age in Yrs.	Study	Frequency cps							
		250	500	1000	2000	3000	4000	6000	8000
Males									
40	ASA	—	1.5	2.0	4.5	9.0	11.5	—	—
36–45	E. K. Co.	0.5	1.0	2.6	4.7	10.4	13.4	14.0	12.4
35–44	Hinchcliffe	1.7	1.7	1.7	2.5	6.5	9.1	9.9	11.0
60	ASA	—	6.5	8.0	18.0	25.0	31.5	—	—
56–65	E. K. Co.	4.4	6.6	9.6	17.1	29.0	35.5	36.6	37.6
55–64	Hinchcliffe	6.5	7.0	5.6	12.1	29.4	34.3	47.0	53.5
Females									
40	ASA	—	4.0	4.0	4.0	4.5	5.0	—	—
36–45	E. K. Co.	3.5	3.8	3.7	3.8	5.8	7.5	9.0	7.4
35–44	Hinchcliffe	1.7	1.7	1.7	2.5	5.5	5.3	6.2	7.2
60	ASA	—	9.5	9.5	12.0	14.0	17.0	—	—
56–65	E. K. Co.	7.5	9.6	10.0	14.2	18.1	20.4	24.3	21.6
55–64	Hinchcliffe	6.5	7.0	5.6	8.7	14.8	19.4	22.3	24.7

* Thresholds in decibels.

threshold for men and women in these age groups, who have had minimal noise exposure and no obvious ear disease.

3. Considering the large number of observations, it is not likely that either the means or the standard deviations will change appreciably as increased data are obtained, providing the groups are well controlled and the instrumentation comparable.

4. There is a significant difference in the effect of age on the threshold of hearing of men and women. We have no acceptable explanation for this difference.

5. Two possible sources of error in the data presented are:

(a) Since many of the examinations were performed on applicants for employment, a possible learning factor of a few decibels may be included in some of the tests.

(b) Some unrecognized noise exposure and/or ear disease may not have been excluded by the screening technique.

6. The remarkable agreement between our findings and those of other observers at different times and in different geographic areas suggest that the magnitude of the change in hearing threshold with age is general and constant.

7. We believe that these data establish a reasonably reliable norm for presbycusis.

Acknowledgments

The study here reported was the result of cooperative efforts of the entire medical staff of the Medical Department of the several plants of the Eastman Kodak Company in the United States. Special credit is due Miss Elaine Dryer and the group of audiometric technicians who conducted the hearing tests and collected the data on which this study is based.

Audiometric calibration and noise measurement data were obtained from a laboratory group under the direction of Mr. Harold Crouch. Various phases of this work were performed by Messrs. D. Andrews, L. Raymond and H. Koyoumjian. Mr. F. L. Goddard measured the environmental noise exposures in the Kingsport, Tennessee plant.

Analysis of the data was carried out by a group under the direction of Mr. Robert Morris after the cards were punched and sorted under the direction of Mr. E. B. Wallace. The technical advice on statistical problems and challenging questions of Drs. Wm. Howe and J. E. Jackson deserve special mention.

The patient services of Mrs. M. Bouton who

prepared the various drafts of this manuscript for publication were invaluable.

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3. ASA Exploratory Subcommittee: *The Relations of Hearing Loss to Noise Exposure, Z24-X-2-1954.* American Standards Association, New York, New York (1954).
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Retired But Not Out

FRANK A. PATTY (left) is shown accepting from Mr. Jack C. Radcliffe, now Past-President, AIHA, the certificate indicating the award of honorary membership in the American Industrial Hygiene Association. This honor was given to Mr. Patty in recognition for his long years of service to the Association and to the profession of industrial hygiene. Mr. Patty, now retired according to the records but decidedly active according to facts, was formerly head of industrial hygiene activities for the General Motors Corporation. He served as General Conference Chairman for the first American Industrial Hygiene Conference which was held in Detroit, Michigan, April 9–12, 1961. He is also engaged in the revision of a well-known book on industrial hygiene.

Using the Sound Level Meter to Evaluate Audiometer Performance

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Maintaining proper calibration of audiometers is a critical problem in industrial audiometry. An audiometer evaluation system and a field calibration procedure are described here in detail. Microphone characteristics and audiometer frequency measurements are discussed in appendices.

Introduction

THERE are only three commonly used techniques for the evaluation of audiometer performance. For industrial audiometry, the order of popularity seems to be as follows: the first and most often performed is a psychological calibration involving testing of one or more persons with normal or other known values of hearing level. This test has been recommended in most discussions on industrial hearing loss[1, 2, 3] and provides some indication of audiometer performance usually at 0 decibel hearing level. The second procedure that is generally recommended involves returning the audiometer to the manufacturer for annual or semi-annual recalibration. This procedure, of course, does not indicate the extent of errors incurred between tests or even in many cases the extent of errors, if any, found at the time of recalibration. The third and most complete procedure is that included in the *Specifications for Audiometer for General Diagnostic Purposes, Z24.5, 1951,*[4] published by the American Standards Association. This standard specifies an earphone coupler that, when used in conjunction with a laboratory standard microphone, allows one to measure the acoustic output of the audiometer earphone under approximately the same conditions that exist when the earphone is placed over the average human ear. This last procedure usually involves microphones and measurement techniques that do not lend themselves readily to field use. The cost of this equipment is sufficiently high to discourage its use for the calibration of a small number of audiometers.

In order to obtain valid audiometric data over long periods of time, the problem of audiometer calibration cannot be overlooked. A need has been demonstrated for a simplified physical evaluation of the audiometer to take the place of the psychophysical test in checking the audiometer between factory or other artificial calibrations. The development of a field calibration technique allowing audiometer evaluation at all hearing level values greater than 0 decibels would have obvious advantages over the psychophysical technique.

Let us consider the possible requirements for a field evaluation technique for industrial audiometry. Industry is concerned with obtaining an accurate base line audiogram in the frequency range between 250 and 4000 cps and monitoring changes in periodic audiograms taken over the frequency range of 250 to 8000 cps. Thus, it seems desirable to develop an audiometer calibration system capable of evaluating the audiometer output quite accurately at frequencies of 500, 1000, 2000, and 4000 cps and providing the ability to monitor changes in output at frequencies outside of this range. It also seems quite desirable to have a system that will allow direct measurement of the acoustic output at all positive values on the hearing level dial. As some ears tested may have sharply sloping hearing level curves, it would be advantageous to be able to measure the actual frequencies being tested.

Based on the apparent need for a simple calibration system that would provide a physical evaluation of audiometers used by industry, an investigation of available sound measuring equipment was undertaken to determine if it could be used to provide the basis of such a system. As such equipment is becoming commonplace in industry, a simple attachment for audiometer evaluation would allow industry to perform field calibrations with a minimum of expense and complication.

With the advent of the improved inexpensive microphones now available on a number of sound level meters, it becomes feasible to modify earphone couplers so that, when used in conjunction with the sound level meter microphone, the combination will provide the proper acousti-

cal impedance to the audiometer earphone being tested. The pressure response characteristics of the combination should allow direct measurement of the sound pressure level produced by the earphone over the frequency range of interest. As the Shure 98B99 microphone is supplied with a large number of sound level meters being purchased by industry, tests were performed to show that it could be applied to audiometer evaluation (Appendix I).

The internal electrical noise levels described in the operating instructions for commercially available sound level meters (SLM) indicate that it is possible to make meaningful measurements of the audiometer acoustic output with the hearing level (HL) dial set at zero and using an octave band analyzer (OBA) to provide filtering around the tone evaluated. Octave band filtering will be adequate at frequencies of 250–2000 cps for most earphones used with audiometers but additional filtering may be necessary outside this frequency range or at negative values on the HL dial. It is assumed here that ambient noise levels present in the testing area do not interfere with the measurement. For higher HL dial values, the problem of interfering electrical and acoustic noise diminishes so that filtering problems become less stringent.

Although some field equipment used for sound measurement is capable of accurate frequency determination, most noise equipment used by industry does not have this capability. Therefore, to complete the SLM, OBA audiometer evaluation system and provide a frequency determining capability not found in commercially available calibration systems, it was necessary to develop a frequency evaluation accessory. This accessory equipment consists of a variable frequency sawtooth oscillator and insert resistor network (see Appendix II), and provides a zero beat indication for frequency determination of the audiometer tone.

Audiometer Evaluation System

As will be discussed in Appendix I, the SLM microphone has an adequate pressure response characteristic for field calibration of audiometer earphones and one can build up a complete calibration system composed of the following items. The first item in the system is a modified type 1 coupler[5] as shown in Figure 1 which, when used with the 98B99 microphone, provides proper acoustical impedance for the audiometer earphone. The second component in this system is a small enclosure (see Figure 2) to help reduce background noise at the coupler. The output of the microphone is fed through a cable to the SLM and OBA used for measuring the sound pressure levels generated by the earphone. Finally, an auxiliary device for determining the frequencies generated by the audiometer may be included.

As a means of testing the evaluation system, the coupler response of a Telephonics TDH 39 earphone determined by the SLM-OBA system may be compared with the response obtained with a laboratory standard microphone using the same type of coupler. The TDH39 earphone was chosen because of its almost universal use on American audiometers of recent manufacture. The frequency response of the TDH39 earphone using the above system is shown in Figure 3. For comparison purposes, the response of the same earphone as determined with a Type 1 coupler in conjunction with a Bruel & Kjaer 4132 microphone is also shown in Figure 3. It can be seen that very close agreement is reached over the frequency range from 250 cps to 4000 cps. Since the field calibration system presents the same acoustical impedance to the earphone as the standard coupler in conjunction with a laboratory standard microphone, it can be used to evaluate audiometer performance using an earphone for which the threshold pressures have been determined on a Type 1 coupler. In the frequency range 250–2000 cps, the difference in threshold pressures for an earphone measured on a Type 1 or Type 9A coupler is insignificant[6] and either set of data may be used. At 4000 cps a correction must be applied if the threshold pressure values for a 9A coupler are to be used for comparison with field calibration results.

Procedure

Allow the audiometer being tested to warm up for 15 to 20 minutes while setting up and calibrating the sound measuring equipment. During the warm-up period it is desirable to listen to the tones generated by the audiometer and note tone interrupter clicks, distorted signals, and abrupt changes in tone level while changing the HL dial. It is usually more convenient to perform all tests with the microphone mounted in the enclosure as shown in Figure 2. An acoustic calibrator is used to set the gain on the SLM and OBA so that correct level indications will be obtained with the microphone mounted in the enclosure. Since there will be a short length of cable between the microphone and the SLM, the effect of temperature changes should be monitored unless appropriate measures have been taken by the manufacturer to eliminate temperature effects on meter indications. As

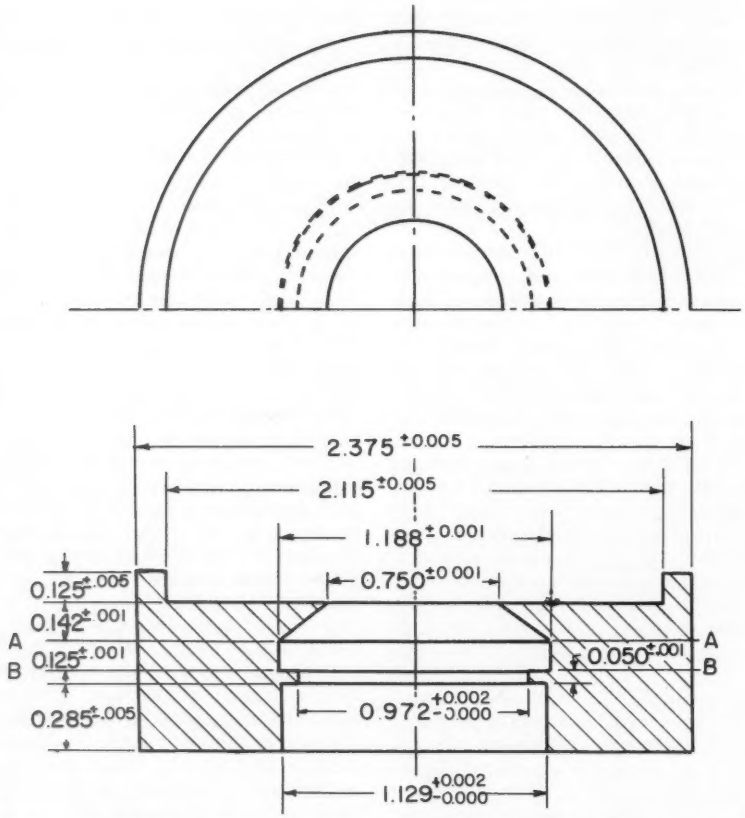

FIGURE 1. Modified Type 1 coupler for use with 98B99 microphone. May be made from either metal or plastic rod. Fabrication in two pieces joined at A or B simplifies construction without impairing performance.

FIGURE 2. Photograph of audiometer evaluation system. Enclosure constructed of ¾" plywood with weatherstrip seal. Top very tightly clamped using window sash latches on all four sides.

the pressure response of the microphone is less sensitive than the random incidence response, the corrections at high frequencies will be smaller, if the SLM is employed using the most uniform electric frequency response available.

After calibration of the sound measuring system, the coupler is placed on the microphone and the system is ready for evaluation of the audiometer. The earphone cushion is removed and the earphone placed on the coupler and held in place with a 500-gram weight or equivalent force.[5] The earphone cushion should be marked so that it can be returned to the same earphone after the measurements have been made. The HL dial is set at 60 db and the tone interrupter switch positioned so that the tone remains on continuously. The sound level produced by the

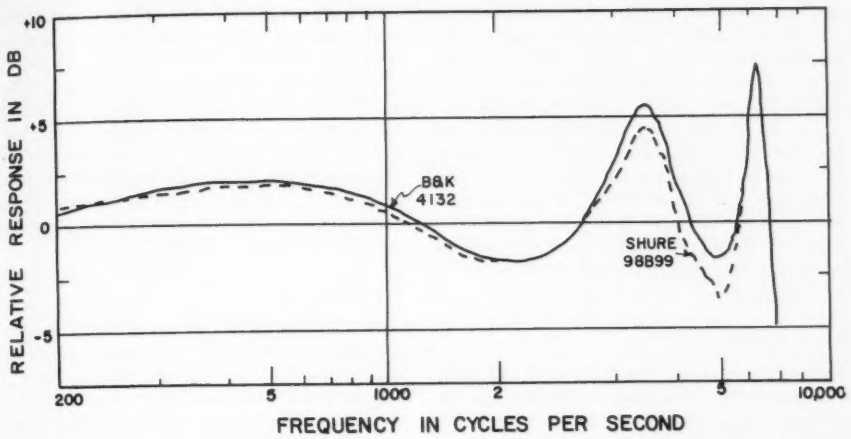

FIGURE 3. Frequency response of TDH 39 earphone as measured with SLM-OBA system using 98B99 microphone and ASA Type 1 coupler with Bruel & Kjaer 4312 laboratory standard microphone.

earphone is determined for each setting of the frequency dial and recorded on a chart or form similar to that shown in Figure 4. If the perpendicular incidence free-field calibration curve of the microphone is known, then appropriate corrections may be determined and included in the charts. The correct value of the earphone output is then determined and compared with

Audiometer Level Test

AUDIOMETER MAKE _____ EARPHONE _____ TESTER _____
MODEL _____ CUSHION _____ DATE _____
SERIAL NO. _____ SLM NO. _____ OBA NO. _____
ACOUST. CAL. NO. _____ MIC. NO. _____

Frequency—Audiometer	125	250	500	750	1000	1500	2000	3000	4000	6000	8000
H.L. Dial Setting—Audiometer											
Gray Level Reading SLM-OBA											
Gray Level Corrections											
Corrected Gray Level Reading											
Desired Level Reading	111.8	99.5	84.1	78.5	77.2	78.0	78.0	75.6	74.3		
Black Level Reading SLM-OBA											
Black Level Corrections											
Corrected Black Level Reading											
Desired Level Reading											

FIGURE 4. Form used to record frequency response data obtained with audiometer evaluation system. This data normally obtained with HL dial set at 60 db. The desired levels shown are those suggested by J. R. Cox and R. C. Bilger, "Suggestion relative to the standardization of Loudness-balance data for the telephonics TDH 39 earphone", *J. Acoust. Soc. Am., 32:* (Aug. 1960).

the desired levels shown on the chart. As the test can be performed inside of the audiometric test room, assuming it meets the suggested maximum ambient noiselevels for 0 db hearing level tests,[7] it will be unnecessary to use the octave band analyzer for measurements at 60 db hearing level. For some audiometric rooms, the presence of high noise levels at very low frequencies may make it desirable to perform the measurements with the A weighting network in the SLM circuit. Appropriate corrections at both low and high frequencies must then be included in Figure 4.

Attenuator Tests

This procedure allows comparison of the audiometer attenuator with those contained in the SLM-OBA. In order to evaluate audiometer output at low HL dial settings, it is necessary to reduce the ambient noise in the coupler to values below the maximum allowable octave band levels for zero db hearing level tests. This may be accomplished by using a small enclosure as mentioned above, or narrow band filtering around the tone being evaluated. For hearing levels down to +10 db, octave band filters should be sufficient. For levels below 10 db, it will be necessary to use narrow band (10% or less) filtering. The analyzer may be set to read correctly at 60 db hearing level using the tone from the audicmeter to set levels. The HL dial on the audiometer is then shifted in 5 db steps and the corresponding readings noted on the analyzer. The SLM attenuator should be used for checking the audiometer attenuator except at HL dial settings yielding acoustic outputs less than 30 db or below the overall ambient noise levels. For less interference from ambient noise, the SLM attenuator may be left at 40 or 50 db and the audiometer output at low HL values checked with the OBA attenuator. At low values of hearing level, it is desirable to monitor the presence of electrical noise and/or ambient acoustic noise by interrupting the audiometric tone and noting the change in reading on the analyzer. As soon as the change is less than 8 db, it is desirable to determine the source of noise by replacing the microphone with a suitable equivalent electric circuit (dummy microphone*) and note the change in readings. If no change in reading is noted, the noise is probably originating in the SLM or OBA and a practical limit has been reached in the attenuator evaluation. An appreciable change resulting from installation of the dummy microphone indicates the presence of ambient noise or excessive noise output from the audiometer circuit. Although it is probably sufficient to monitor the audiometer attenuator characteristics at only one frequency and using only one earphone, the original measurements on the audiometer should include attenuator checks at 250, 500, 1000, 2000, and 4000 cps using both earphones. Measurements may be made at all values on the HL dial but are subject to the limitations imposed by the ambient noise present and the type of anlyzer being used. Attenuator characteristics may be recorded on a form similar to that shown in Figure 5.

Summary

The audiometer field calibration system as described in this paper will provide a means of monitoring audiometer performance on a periodic basis without the problems associated with maintaining a normal hearing group of non-exposed ears used in the psycho-physical calibration. This method does not eliminate the need for daily evaluation of audiometer performance by the audiometric technician. It does, however, provide a physical measurement of the audiometer characteristics and thus provides a basis for determining correction factors for the audiometric data taken between annual or semi-annual calibrations by the audiometer manufacturer. It is not recommended that this field calibration procedure be used as a basis for weekly or monthly adjustment of audiometer functions. Such frequent adjustment of the audiometer makes it virtually impossible to follow the trends of the changes in audiometer performance. Also, adjustment of the audiometers should be followed by factory or ASA standard recalibration when one considers the legal aspects of industrial hearing loss. By using this field calibration procedure it is possible to determine when the audiometer is introducing errors into audiometric data of such magnitude that repair and recalibration is desirable. The magnitude of error tolerated may be arbitrarily determined by the audiometer user, but should probably not be greater than the tolerance limit set by the ASA standard for screening audiometers. Since the error may vary for different frequencies, some judgement must be used in applying even this criterion.

Only one type of microphone has been discussed because it is readily available and supplied as standard equipment on several sound measuring instruments. The intent was not to limit the procedure to equipment using this microphone, since many other microphones have suitable acoustical characteristics for this type of measurement. For example, one equipment manufacturer using dynamic microphones will

Audiometer Attenuator Tests

AUDIOMETER MAKE _____ EARPHONE _____ TESTER _____
MODEL _____ CUSHION _____ DATE _____
SERIAL NO. _____ SLM NO. _____ OBA _____
ACOUST. CAL. NO. _____ MIC. NO. _____

H.L. Dial Setting	Audiometer Frequency ( ) CPS			( ) CPS			( ) CPS		
	SLM—OBA Reading	Error		SLM-OBA Reading	Error		SLM-OBA Reading	Error	
		Gray	Black		Gray	Black		Gray	Black
100									
95									
90									
85									
80									
75									
70									
65									
60									
55									
50									
45									
40									
35									
30									
25									
20									
15									
10									
5									
0									

FIGURE 5. Form used for recording audiometer-attenuator data.

supply an appropriate coupler to allow measurement of audiometer performance.[9] One cannot however, use any readily available microphone and expect accurate results without making the type of microphone evaluation described in Appendix I of this article.

The accuracy of this calibration technique is limited by the accuracy and stability of the microphone characteristics and associated electronic equipment as is the case with the ASA systems. Over the limited frequency range important to speech reception, the shape of the frequency response curve seems to remain constant with changes in absolute sensitivity and accuracy may be maintained with the help of a calibrated sound source such as the General

Radio Acoustic Calibrator or equivalent. From evaluation of a sample 12 microphones it appears that uniformity of frequency response allows accuracies of ±1 db in audiometer evaluation at 250, 500, 1000, 2000, and ±2 db at 3000 and 4000 cps. Knowledge of the microphone's free-field frequency response and electrical response of the measuring instrument will allow uniform acuracy over this entire frequency range. Under these conditions accuracy is limited by the acoustic calibration system used to establish absolute sensitivity of the sound measuring system.

Acknowledgment

The author wishes to acknowledge the help and advice given by J. R. Cox, Jr. of Central Institute for the Deaf and Ervin Gross of General Radio Company.

Appendix I

Microphone Characteristics

In order to show that one could measure the acoustic output of audiometers and maintain sufficient accuracy and reliability to warrant the use of field calibration system utilizing sound measuring equipment, it was necessary to evaluate the characteristics of the microphone commonly supplied with this equipment. The Shure Brothers microphone Model 98B99 was chosen because of its size, availability and acceptance by manufacturers of sound measuring equipment.

In order to determine the acoustical impedance of the microphone, the procedure described by Cook[10] and L. Mawardi[11] was utilized. This procedure consists of measuring acoustical impedance by substituting a known acoustical impedance for the microphone in a cavity driven with a constant velocity sound source. The change in pressure amplitude, and phase is noted and the unknown impedance calculated from the measurements. The actual procedure used involved a Type 1 coupler, a TDH39 earphone as a sound source, and the 98B99 microphone was replaced by the size cavity such that there was no change in amplitude or phase of the pressure inside the coupler with the interchange of microphones and cavity. By this procedure, it was found that the equivalent volume of the 98B99 microphone was approximately 1.2 cubic centimeters and remained constant over the frequency range between 250 cps and 4000 cps. The measurement became somewhat difficult at 4000 cps due to wave effects inside the cavity. The effective acoustic impedance of the TDH39 earphone is such that a relatively large change in volume in the coupler does not yield a large change in coupler pressure.

Having determined the acoustical impedance of the microphone, it was then necessary to determine that the pressure response of the microphone did not vary greatly over the frequency range of interest, thus making it necessary to determine the individual pressure response for every microphone used. Using an appropriate coupler designed to present a 6 cc cavity to the earphone when used in conjunction with the 98B99 microphone, the response of a TDH39 earphone was determined using 12 different microphones. The results of these measurements are shown in Figure 6 and indicate the uniformity of microphones selected by the manufacturers. It can be seen from this curve that accuracies of ±1 db are easily obtainable in the frequency range of 250 to 2000 cps and that the spread of data at 4000 cycles indicates accuracies in the order of ± 2 db no matter which microphone of this type one picked off the shelf and installed on the SLM and calibrated with an acoustic calibrator.

In order to determine whether the pressure response of the microphones was uniquely related to the free-field response, the same 12 microphones were calibrated at perpendicular incidence in a free-field and the correlation between free-field and pressure response was found to be high up to approximately 6000 cps.

Using the above techniques it was possible to determine the pressure response of the 98B99 microphone and the correction factors that may be subtracted from the perpendicular incidence free-field curve to obtain the pressure response curve as shown in Figure 7.

As the free-field response curve of the microphone is usually determined by the SLM manufacturer in selecting his microphones, it should be possible to obtain correction data so that accuracies of ±1 db in audiometer calibration may be obtained over the frequency range of 250 to 4000 cps.

The microphone described in this Appendix may be used to replace the large older crystal microphone supplied with early sound measuring equipment. The combination may be used to perform audiometric evaluations as described above. Because of the difference in electrical characteristics of the newer microphones, the low frequency response (below 200 cps) of such a combination may suffer some degradation. This loss at low frequencies is unimportant in audiometric measurements but may result in inaccurate low frequency field measurements.

Having established the acoustical character-

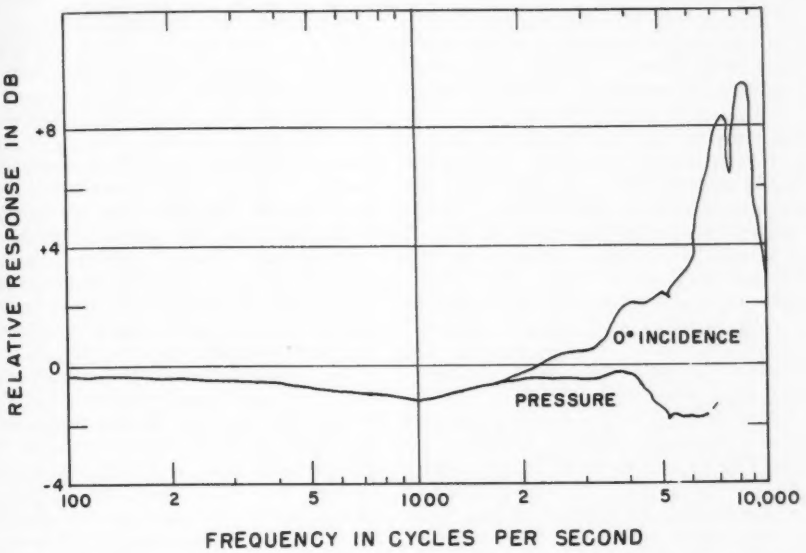

FIGURE 6. Free field perpendicular incidence and pressure response of Shure 98B99 microphone.

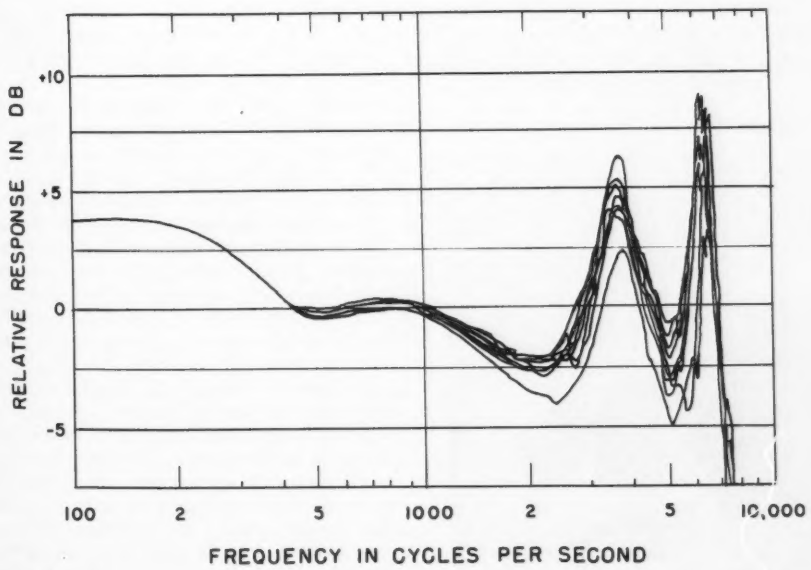

FIGURE 7. Frequency response of TDH 39 earphone as determined using 12-98B99 microphones, each installed on same SLM and acoustically calibrated to read correctly at 400 cps.

istics of the microphone, it is necessary only to fabricate a coupler providing a combined volume of 6 cubic centimeters in order to make valid measurements of audiometer output. There are two types of couplers currently described in the American Standard Association publications and either of these might be modified for use with the 98B99 microphone. Since there are data relating the coupler pressures of the TDH39 earphone and the Type 9A coupler, the first attempt at calibration involved a modified Type 9A coupler. After a few tests, several disadvantages of the 9A coupler became quite apparent. The acoustic seal between the earphone and the coupler is poor so that low frequency background noise becomes quite a problem when the acoustic output of the earphone, corresponding to the low hearing level values, is measured. Also, the conversion of building vibration into the pressure fluctuations as a result of the earphone and weight bouncing on the coupler creates additional masking noise at low frequencies. Although it was apparent that valid measurements could be made using a modified Type 9A coupler in conjunction with the microphone, it was decided to investigate the use of the Type 1 coupler as described in American Standards Z24.9, 1949. The difference between the two couplers is insignificant over the frequency range of interest. The Type 1 coupler is a more desirable shape for field use and it was adopted for the field calibration system. The final design of the coupler used in the audiometer calibration system is shown in Figure 1.

Appendix II

Audiometer Frequency Measurement

To measure the frequency of the tones produced by the audiometer, a zero beat-frequency technique is utilized in which the fundamental and harmonics of a sawtooth oscillator are mixed with the signal from the audiometer to produce beats. It is possible, by varying the frequency of the sawtooth oscillator, to observe a zero beat position indicating that the two oscillators are producing the same frequency. By calibrating the frequency of the sawtooth oscillator fundamental, it is possible to obtain a frequency measurement over the range of interest. The fundamental of the sawtooth oscillator may be varied from 450 cps to 550 cps and read with an accuracy of one cps. This means that at 4000 cps the eighth harmonic will vary from 3600 cps to 4400 cps and may be read with an accuracy of approximately eight cps.

FIGURE 8. Photograph of sawtooth wave generator and insert resistor assembly.

To allow beating the sawtooth oscillator with the signal from the audiometer an insert voltage technique is used and the zero beat point is observed on the SLM. The insert voltage resistors are contained in the small box that is connected between the SLM microphone cable and the SLM. The sawtooth generator that may be used is a slightly modified version of that shown on page 142, Figure 13-12 of the *General Electric Transistor Manual*, fourth edition, and the frequency may be varied by changing the value of a resistor in the capacitator charging circuit. A vernier dial allowing the determination to one part in a hundred is used to control the resistor and the dial is calibrated in one cps increments from 450 to 550 cps.

In order to be sure that the sawtooth oscillator is operating at the right frequency it may be in turn matched to upper harmonics of 60 cps AC line signal. It is possible to calibrate the oscillator at 480 and 520 cps by using an appropriate harmonics of the 60 cps line frequency. The transistor-oscillator is quite simple and seems to be relatively stable. A photograph of the oscillator is shown in Figure 8. For microphone systems utilizing a preamplifier directly connected to the microphone the insert resistor may be inserted between the pre-amplifier and the SLM. Of course, a special cable will be required in placing the microphone in the enclosure as described.

In order to obtain beats between the audiometer tone and the appropriate harmonics of the sawtooth generator, the levels of the signals must be approximately the same and the frequencies within a few cycles per second of each other. If these conditions are met, quite obvious fluctuations (beats) in the SLM reading will be obtained. The frequency of the beats will increase if the sawtooth harmonics are shifted in frequency above or below the audiometer frequency. As the same frequency is approached, the beats will become slower and disappear en-

tirely when the frequencies are identical (zero beat).

After calibrating a sawtooth oscillator with the appropriate harmonics of the 60 cps line using the zero beat technique, the sawtooth oscillator is set at 500 cycles. The output of the audiometer is adjusted to yield approximately the same level on the SLM or OBA as that produced by the sawtooth generator. The frequency of the sawtooth oscillator is then varied above and below the 500 cps point and the oscillator frequency at zero beat noted. If there is no indication of beats, the level of the audiometer tone should be reduced and another attempt made. It may be necessary to reduce the lower harmonics of the sawtooth signal in order to observe the beats. This is accomplished by filtering both the signals through the analyzer and observing the beats on the analyzer meter. Again, the two signals must be of approximately the same level and this is accomplished by adjusting the audiometer output until the same indication is obtained when either signal is present.

With some audiometers a zero beat point will be observed both above and below the midpoint of the sawtooth oscillator range, indicating that two harmonics of the sawtooth oscillator fundamental may be shifted so as to beat with the audiometer signal. By noting both zero beat points, it is possible to determine the frequency of the audiometer. This situation cannot occur when the audiometer is within the tolerance limits specified by the American Standards Association.

For those microphones having sharp fluctuations in their response curves it would be desirable to make the frequency determinations first, if corrections are going to be made for these variations. In most situations we are only interested in determining that the audiometer is within the American Standards Association tolerance limits or monitoring the changes as a function of time and therefore frequency determination may be done at any point in the evaluation program or even omitted.

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Industrial Hygiene Certification

THE AMERICAN BOARD OF INDUSTRIAL HYGIENE invites inquiries from those who are interested in applying for voluntary certification in the profession of industrial hygiene. Certificates will be issued on the basis of an examination to those who have eight years of prictice, following a suitable baccalaureate degree. No examination will be required of those who have fifteen years of practice with recognized contributions to the field, following acceptable education. Certain specialists within the field will be certified when one-fourth of their time has consistently been devoted to application of their specialty to industrial hygiene. A brochure describing the certification program, and giving more details of eligibility will be sent to those who direct inquiries to Henry F. Smyth, Jr., Secretary-Treasurer, American Board of Industrial Hygiene, 4400 Fifth Avenue, Pittsburgh 13, Pennsylvania.

The Board was chartered as a non-profit corporation under the laws of the Commonwealth of Pennsylvania in September 1960. The incorporators were selected by the American Conference of Governmental Industrial Hygienists and the American Industrial Hygiene Association from among their respective memberships. They are John C. Soet, Chairman; Lester V. Cralley, Ph.D., Vice-Chairman; Henry F. Smyth, Jr., Ph.D., Secretary-Treasurer; and Edgar C. Barnes, William R. Bradley, Allan L. Coleman, Hervey B. Elkins, Ph.D., Louis F. Garber, Thomas F. Mancuso, M.D., Kenneth M. Morse, James H. Sterner, M.D., and Charles D. Yaffe.

Speech Transmission through Respiratory Protective Devices

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The articulation index, or measure of the intelligibility of the spoken word, has been determined for 15 respiratory protective devices in common use. These values have significance in the ability to communicate when wearing respiratory protection.

FOLLOWING the observation by one of the Research Laboratory consultants, Dr. Louis Navias, that the speech characteristics of respirators were so poor that personnel wearing them in a toxic atmosphere were forced to remove the masks from their faces in order to talk, a survey was made of the existing knowledge on the speech characteristics of such devices. The paucity of firm data suggested that an impartial investigation of this subject should be undertaken with the view of (1) determining what respirator in each class had the best characteristics of speech transmission, and (2) suggest to designers and manufacturers of such devices that attention be given to speech characteristics.

At our request and expense, R. B. Tatge of the General Engineering Laboratory made a series of tape recordings during the time C. P. Malone spoke a series of 10 test sentences while wearing each of the respirators. Between each set of sentences spoken with the respirator, the sentences were repeated without it. The subject wore ear plugs, and he attempted to keep his voice level as nearly constant as possible. The pickup microphone was placed approximately 15 feet from the subject in a laboratory sound room.

The tape-recorded data were analyzed by passing them through a one-third octave band filter, then electronically determining the mean-square level of the signal in each frequency for each set of 10 test sentences. This level, expressed in decibels, was taken to be proportional to the energy level in that frequency band.

The insertion loss of a given respirator was taken as difference between the arithmetical average of the levels of the runs on either side of the respirator test, and the level produced while wearing the respirator. The insertion losses (in db) of the various respirators are plotted in Figures 1 through 8. It should be noted that some respirators show a negative insertion loss (which is a gain) at low frequencies, which may be due to resonance within the respirator at those frequencies, thereby increasing the radiated sound energy (see reference 1).

Prediction of speech intelligibility is based on calculation of the articulation index, which is a measure of the percentage of speech sounds which a listener will perceive correctly. Experiments have shown how the articulation index is related to the intelligibility of isolated monosyllabic words, sentences, etc. Due to the built-in redundancy in speech the intelligibility of monosyllabic words is greater than the articulation index, while sentence intelligibility is higher still. The relationships are graphed in Figure 9. (See reference 2.)

In the calculation of articulation index, the speech spectrum of a typical male voice is broken into 20 frequency bands which have been found to contribute equally to speech intelligibility. Then one postulates or measures the background noise in the listening environment in each frequency band, and also determines the level of the reverberant speech, that is, those speech sounds which reach the listener's ear after one or more bounces rather than by a direct path. (See reference 3.) The reduction of intelligibility in a noisy environment is familiar; the reduction due to reverberant speech is often a problem in large rooms with relatively little sound absorption. If direct speech sounds are much higher than the background noise and the reverberant speech level, the articulation index will be high, but as the speech sounds become closer to the background noise or reverberant speech sounds, the ear will hear less information correctly and articulation index will drop.

Communications systems with low articulation indices are not uncommon, but often go unrecognized since sentence intelligibility remains high as long as the articulation index is above 0.4 to 0.5. If transmission of monosyl-

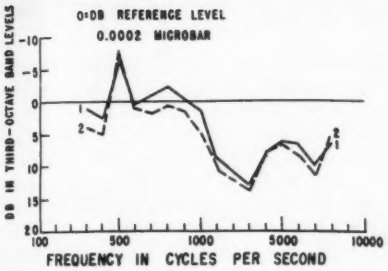

Fig. 1

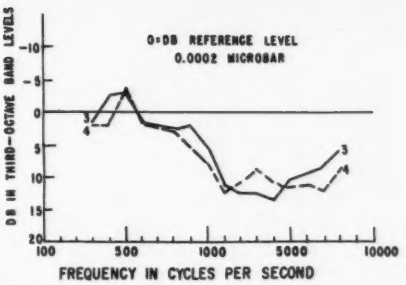

Fig. 2

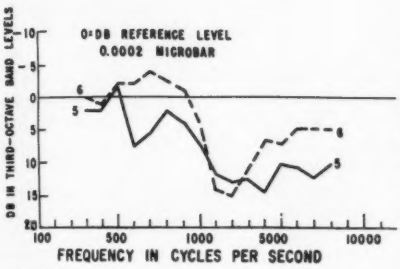

Fig. 3

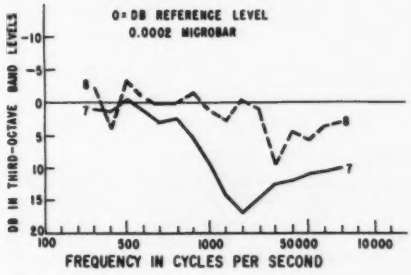

Fig. 4

FIGURES 1 THROUGH 4. Plots of insertion losses at various frequencies for respirators 1 through 8. The numeral identifying each curve corresponds to the designation of that respirator in Table I and Figure 10.

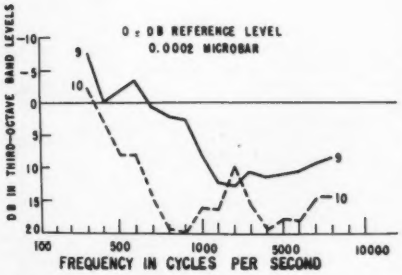

Fig. 5

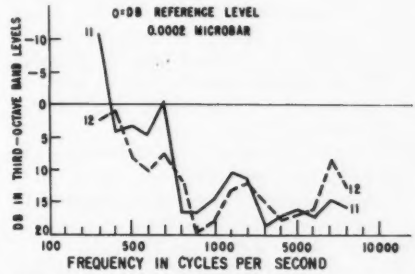

Fig. 6

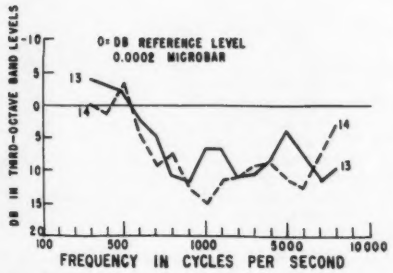

Fig. 7

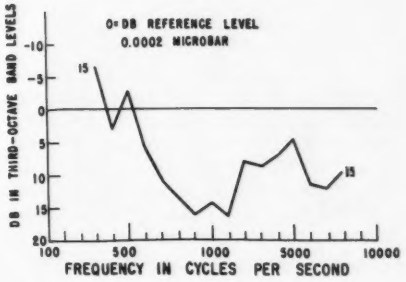

Fig. 8

FIGURES 5 THROUGH 8. Plots of insertion losses at various frequencies for air-supplied respirators, gas masks, and self-contained breathing apparatus numbers 9 through 15. The numeral identifying each curve corresponds to the designation of a specified breathing apparatus in Table I and Figures 11 and 12.

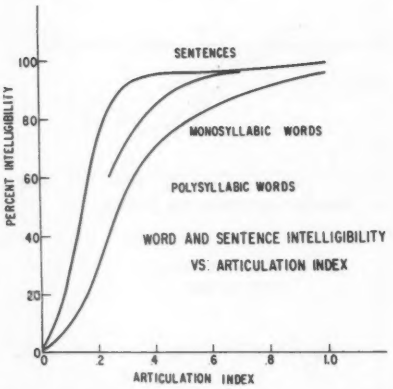

FIGURE 9. Relative intelligibility vs articulation index of sentences, monosyllabic words, and polysyllabic words.

lables is important, such as might be the case in emergency situations where single word commands were necessary, a higher articulation index would be required.

The articulation index for each respirator has been calculated for each of three conditions:

(1) Face-to-face communication between two people using raised voices, ten feet apart, in a typical office (background noise is measured in a typical office in Building 23; reverberant speech level is based on the acoustics of laboratory area Building 37, Room 620).

(2) Face-to-face communication between two people shouting one foot apart, in a large manufacturing area (background noise measured in Building 273).

(3) Same as 2, except two feet apart.

In both situations we assume that the listener is not wearing ear protection, and that any respirator he wears does not cover his ears. Results are shown in Table I.

In the office, speech communication is limited mainly by the reverberant speech level, since background noise is fairly low. As a result, the articulation index calculated does not vary much from respirator to respirator, or even where no respirator is worn, since the ratio of direct speech level to reverberant speech level is constant. On the other hand, the articulation index does vary markedly in the manufacturing area, which is typically noisy and not too reverberant.

The various devices tested are pictured. Figure 10 includes devices usually called respirators, and numbered 1 through 8. Figure 11 includes the air-supplied respirator and the devices usually called gas masks, numbered 9 through 12. Figure 12 includes the self-contained breathing apparatus, numbered 13 through 15. For simplicity, the photographs of the self-contained breathing apparatus show only the face-pieces; in the actual tests the devices were worn as intended and were in use.

Except for the civil defense masks, all the devices tested are commercially available at the present time, and are believed typical of devices of these classes. The civil defense masks, which are intended for use by civil defense personnel after enemy attack, for protection against chemical, biological, and radiological warfare agents, are stockpiled in government warehouses by the Office of Civil and Defense Mobilization, Battle Creek, Mich., for issue at some future date.

In reviewing these data, it should be noted that absolute predictions of articulation are not

TABLE I

Articulation Index for Various Devices

Device	Office Area 10 ft. raised voice	Factory Area 1 ft. shouting	Factory Area 2 ft. shouting	Control (%)
1. Dust respirator*	0.46	0.40	0.21	50
2. Gas and vapor respirator* (chemical cartridge)	0.45	0.36	0.17	41
3. Dust respirator*	0.45	0.33	0.14	34
4. Gas and vapor respirator* (chemical cartridge)	0.45	0.30	0.12	28
5. Combined ultrafilter respirator with eye prot.*	0.44	0.30	0.12	28
6. Ultra-filter respirator	0.46	0.40	0.20	50
7. Gas and vapor respirator* (chemical cartridge)	0.43	0.26	0.10	25
8. Infrared (heat) respirator	0.47	0.52	0.32	80
9. Air-supplied half-mask respirator*	0.45	0.33	0.14	34
10. Civil defense V-800 mask (O.C.D.M.)	0.36	0.13	0.03	7
11. Chin-style canister-type gas mask	0.39	0.17	0.06	14
12. Universal type-N canister-type gas mask*	0.41	0.15	0.03	7
13. 10-minute demand-type air breathing apparatus	0.47	0.35	0.16	33
14. 45-minute oxygen generating breathing apparatus*	0.46	0.29	0.10	25
15. 30-minute demand-type air breathing apparatus*	0.44	0.28	0.10	25
16. No respirator worn (control)	0.48	0.61	0.41	100

* Indicates Bureau of Mines approved device.

For description of Bureau of Mines Approval system, see Information Circ. 7792, Bureau of Mines Approval system for Respiratory Protective Devices, by S. J. Pearce, June 1957. Currently approved devices are listed in Information Circ. 7885 and supplement to I.C. 7885.

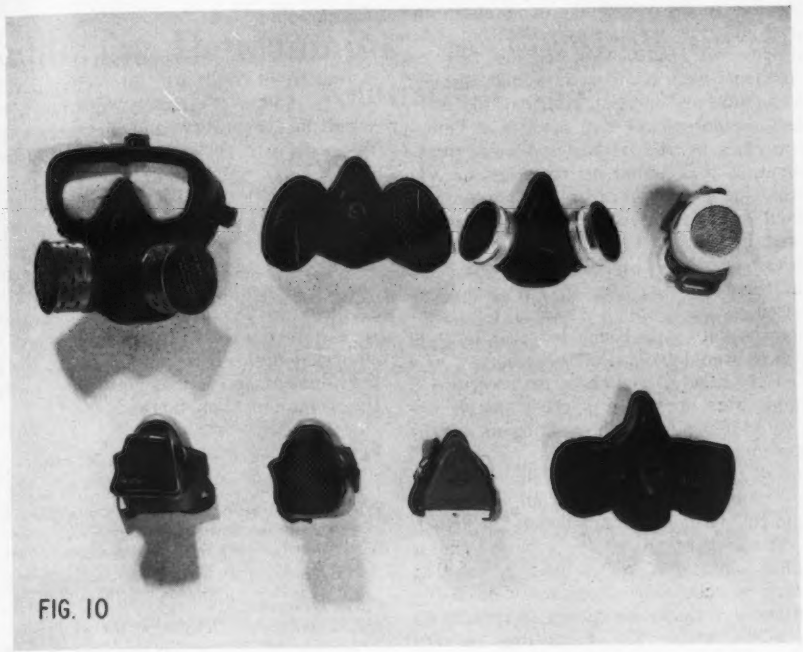

FIGURE 10. Photograph of respirators tested.

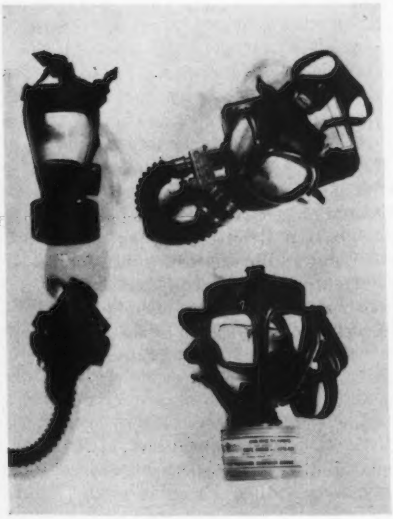

FIGURE 11. Photograph of air-supplied respirators and gas masks tested.

FIGURE 12. Photograph of masks of self-contained breathing apparatus tested.

possible due to the variability of speakers and listeners and the learning process that have taken place with both. Also, the insertion loss measurements were made with a single subject, and were run only once. In addition, the insertion loss measurements may have been limited in some cases by the background noise in the test room, so that actual insertion loss may be somewhat higher than measured. Therefore, the predicted articulation scores should not be interpreted literally, but should be taken as an indication of the probable effectiveness of speech communication under the conditions postulated.

From the data it is concluded that most of the devices would be satisfactory for use in a quiet environment if sentences or prearranged commands were used. Use of other speech material would depend upon how stringent are the requirements for accuracy.

Many of the devices would preclude effective speech communication of any kind in a noisy environment. It should be noted that the articulation index was calculated for a person shouting at 1 ft and at 2 ft from a listener, and that conversing at such short range would probably be impossible in many emergency situations. At longer ranges, intelligibility would drop to very nearly zero.

Conclusions

In conclusion, it is suggested that speech characteristics of respiratory protective devices constitute another parameter which must be recognized if the utility and limitations of such devices are to be fully appreciated. (See reference 4.)

As a practical solution to the problem, especially where self-contained breathing apparatus is worn, the use of telephones in which the transmitter fits into the facepiece of the mask, and the use of compact two-way radio with the microphone in the facepiece, have been exploited to a limited extent. Increased interest in this subject doubtlessly would encourage the further development and use of better and more effective communication methods.

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Air Sampling Instrument Manual

THE ACGIH AIR SAMPLING INSTRUMENT MANUAL is a valuable reference source for everyone engaged in air sampling. It is an up-to-date compendium of instruments for the industrial hygiene field, containing comprehensive descriptive information on the uses, operating principles, physical descriptions, performance data, commercial source if any, operating instructions, and maintenance instructions for almost all of the air sampling instruments currently in use in the United States. In addition, it contains authoritative discussions on air sampling techniques and theory by distinguished authors including Professors Leslie Silverman of the Harvard School of Public Health and Theodore Hatch of the University of Pittsburgh School of Public Health.

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Guide for Determining Specifications in the Use of Acoustical Tile

BRUCE J. HELD

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Acoustical tile is not a "cure-all" for all types of noise annoyance problems. Selection of the proper type for a given condition is essential to obtain maximum benefit for the amount of money spent. The author has presented the major items to consider in tile selection and has listed specifications for some examples which are common to industry and business. A method for specifying absorption qualities is introduced.

Introduction

THE indiscriminate use of acoustical tile has long been a source of dissatisfaction to both the contractor and the user. Lack of adequate specifications has often resulted in the misexpenditure of thousands of dollars through the ineffectual application of noise control material.

Too often, the most common approach to a noise annoyance problem is solicitation of a cost estimate from a maintenance engineer or a tile vendor. The "treatment" usually results in the application of the prettiest or most inexpensive tile to the entire ceiling area of the problem room. More often than not a definite change results in the acoustical behavior of the room, but the final conclusion is that the original noise problem is not corrected satisfactorily. Then there is the unfortunate but common example where an annoyance problem exists in a private office caused by a noisy hallway or adjoining business machine office. A common "correction" is the application of tile in the private office. After installation, the bewildered occupant can detect little or no improvement and in some cases actually senses an increase in the annoyance noise. What, then, can be done to avoid some of these pitfalls? The answer here is not simple nor can a generalized solution even be attempted. However, a careful review of the basic concepts of the nature of noise problems will be well rewarded. The first aim is to see if acoustical tile is even necessary. If it is needed, careful consideration of how the most satisfactory results can be achieved for the least amount of money, will pay big dividends.

Nature of Noise Problem

There are two basic categories of noise problems: those which involve a damage risk hazard and those which constitute an annoyance problem. Results of uncorrected noise which can cause ear damage are all too apparent—lowering of personnel morale, loss of hearing, and large amounts of money paid out for workmen's compensation. This subject has been treated extensively elsewhere and will not be discussed here.

Character of Annoyance Noise

1. *Distraction.* Where concentration or involved thinking is required, the character of a noise is as important as its volume or level in determining whether an annoyance problem exists. The reason for this is the nature of the human ear which is very particular in what it will allow to go unnoticed and what it will register as important. A background noise containing pitch notes is more distracting than a broad-band noise at the same sound pressure level. For example, a waterfall, a running stream, a fan or an air conditioner can be producing fairly high noise levels and hardly be noticed, but let a squeak occur in the fan, for example, and it can be quite distracting. Then again, a background consisting of a periodic noise is not nearly so disturbing as a random-occurring noise. A loud clock ticking next to someone in a room is barely noticed, but if the man in the upstairs apartment drops a shoe, the common reaction probably would be to listen for the other one to drop. Another type of distraction is the situation where the man at a neighboring desk taps his pencil in a random fashion while he thinks.

Speech noise is also very distracting even at low levels because it communicates intelligence to which the ear is conditioned to respond and thus excites interest and probably causes complete distraction.

2. *Communication.* If a noise is hindering communications, again its character, as well as its level, must be considered. This is primarily due to the spectrum shape of speech energies. In the speech spectrum, vowels have comparatively high sound energies at low frequencies, whereas consonants have lower sound energies at high frequencies.[1] However, consonants convey the intelligence while vowels are merely fillers (*i.e.*, bit, fit, sit, wit). It is, therefore, necessary to reduce high frequency interfering noise to allow the consonants to be distinguishable.

Another important phenomenon, called masking, must be considered to more fully understand the communication interference problem. Masking is an apparent audible interference caused by low-pitched noise. The masking effect was first mentioned by A. A. Mayer[2] when he stated that a low-pitched tone will mask a higher-pitched tone at the same sound levels, but a high-pitched tone will not mask a lower-pitched tone. Also, "in general, as the tone becomes more intense, the low tones will become more prominent because the high tones are masked".[3] It can be seen then that the consonants, which convey intelligence, may be unable to compete with a low-pitched interfering noise. Thus, if intelligible conversation is important, the high-frequency character of background noise must certainly be taken into account, but the masking effect of the low frequencies can also be a serious deterrent to oral communication.

On the other hand, it is entirely feasible to turn this masking effect to advantage. This beneficial effect is an artificial correction of a distracting noise, by the generation of a broad-band, low-frequency noise at a level, just below the point of distraction. A simple example was the case of one of our men at the National Reactor Testing Station, Idaho who chose to turn on his desk fan even though it was a cold winter day. When asked to explain this peculiar procedure, he said that by turning on the fan he was able to drown out a conference which had been annoying him in an adjoining room. The fan, obviously, did not distract him, whereas the adjoining conversation did.

3. *Working Environment.* What effect does annoying noise have on the working environment? J. S. Parkinson in the January 1955, issue of Noise Control[4] stated, ".... it was generally believed that noisy working conditions produced definite losses in efficiency. This was supported by the almost unanimous subjective testimony of persons who had experienced the benefits of acoustical treatment." If, then, an efficiency loss is experienced from distracting noise, business and industry will certainly gain financially by reducing it. The question now arises as to how far noise should be reduced to avoid annoyance.

Leo Beranek, after making studies on the "maximum noise levels at which office personnel feel that they can accomplish their duties without loss of performance," developed a set of NC Curves (Noise Criterion Curves).[5] These curves represent the spectrum shape of a tolerable noise environment for various job types and are the criteria upon which the acoustical portion of the suggested specifications in this paper are based.

Location and Type of Source

When a noise problem arises, it should be recognized and analyzed in terms of; first, can the noise be corrected at the source, and, if not; second, can the source be isolated and, again, if not, finally, how can the environment be corrected to reduce annoyance. Many problems can be and should be corrected at the source, usually at a great monetary savings. However, many things, such as people, cannot be controlled either at the source or by isolation in a practical way and control of the environment must be considered.

In terms of isolating the source, the transmission loss concept can be the key to many noise correction problems. Transmission loss can generally be regarded as the reduction of a sound in passing through a partition. A plywood partition, for example, will have considerably less effect in insulating against a noise than a concrete block wall. Strict attention to this concept in the initial planning of a facility may greatly reduce many noise control expenditures which would have to be paid after the building was occupied and found to be unsatisfactory.

Details of Correcting Environment

1. *Room Acoustics.* The basic fundamentals of room acoustics must be taken into consideration when correcting the noise environment. The most encompassing factor would be the reverberation time which is "the time required for a specified sound to die away to one thousandth of its initial pressure, which corresponds to a drop in sound-pressure level of 60 db".[6]

In general, if the reverberation time is long, any sound or noise will be sustained and add in level to the next initiated sound, thus, effectively increasing the over-all level. There is also a psycho-acoustic phenomenon associated with a noise in a highly reverberant environment. This effect tends to make any noise more annoying and fatiguing because the listener is unable consciously or unconsciously to locate the source. However, with a lower reverberation

time, the actual noise level is lower and the apparent noise level is even lower because the listener can now locate the source.

Flutter echo, (a multiple echo from a sound impulse reflecting back and forth between two reflective walls)[7] must also be considered as it has the result of lengthening the reverberation time and hence making any treatment less effective.

Other factors affecting the reverberation time will be the room shape and air absorption. Room shapes where one dimension is a certain multiple or sub-multiple of another dimension will tend to enhance particular frequencies and again effectually increase the reverberation time. Air absorption, which "depends principally on the frequency of the sound wave, the relative humidity, and the temperature,"[8] can be significant in lowering the reverberation time in dry climates.

Finally, the room furnishings have a secondary but significant effect on the reverberation time. Drapes, rugs, furniture, and people can absorb much noise. Books on shelves are excellent absorbers. Acoustical tile in a high ceilinged library or lawyer's office would, in most cases, be a complete waste of money.

2. *Methods of Controlling Distraction.* Two ways of reducing noise annoyance when correcting the environment are absorbing the noise or creating an artificial noise to effect a masking of the annoyance. Masking should be carefully considered as a possible solution before turning to absorption. Often times, increasing the ventilation noise up to a desirable NC Curve may be far cheaper and just as effective as installing absorbers.

3. *Details of Using Absorption Approach.* When absorption is found to be the most economical and acceptable method of control, it is important that the right absorber be chosen, so that the frequency ranges that must be absorbed are covered adequately. For example, panel absorbers do an excellent job on the low frequencies and "functional absorbers" are good from an economic standpoint and flexibility of movement. Other mechanisms can be found for additional types of applications. If acoustical tile is chosen as the answer to a particular problem, then the tile must be considered very carefully in terms of its acoustical properties.

Choosing Acoustical Tile

Placement

Location and amount of tile to be used is important both in effectiveness and cost. Complete coverage of the ceiling is not necessary unless desired for aesthetic appeal. However, partial wall coverage usually is essential for maximum benefit from the tile. A rule of thumb regarding wall coverage is that walls usually need treatment if the ceiling height is more than one-half of the smaller horizontal dimension.[9]

Mounting

The manner in which the tile is mounted plays a large part in the effectiveness of the tile in the different frequency ranges. Various types of mountings have been standardized by the Acoustical Materials Association to determine the effectiveness of the title as a function of the mounting.[10] For example, one tile cemented to plaster board with an ⅛-inch air space has sound absorption coefficients as listed below beside the number 1 mounting while the same tile mechanically mounted on special metal supports has the coefficients as listed beside the number 7 mounting.

Mounting	Sound Absorption Coefficient					
	Frequency (cps)					
	125	250	500	1000	2000	4000
1	0.13	0.24	0.99	0.90	0.81	0.59
7	0.66	0.59	0.72	0.83	0.83	0.65

Thus it can be seen that this tile would be more effective with a number 1 mounting on a noise condition in the 500–1000 cps range, but quite poorly in the 125–250 cps range. However, a number 7 mounting would greatly improve the tile's efficiency in the 125–250 cps range, but would lower it somewhat in the 500–1000 cps region.

Absorption Spectrum

As was indicated above, absorption at a particular frequency is very important in the selection. The effectiveness of a tile in the 125, 250, 500, 1000, 2000, and 4000 cycles per second range is indicated by the term SAC (Sound Absorption Coefficient). For simplification purposes, a SAC of 1.00 can essentially be considered 100% absorption of all noise which strikes the tile in that particular frequency range.

Many people, however, purchase tile according to its NRC (Noise Reduction Coefficient) and often this is the only figure listed by the manufacturer. The NRC is an average of the SAC's from 250, 500, 1000, and 2000 cps range. In many cases the NRC value is adequate. However, many instances do occur where a tile is purchased which is less effective than another

similarly-priced one. For example, a tile might be specified to have an NRC of 0.70 to correct a predominantly low frequency noise condition, but the SAC's in the four frequency ranges might be 0.35, 0.60, 0.90, 0.95. However, there are existing tiles which have SAC's all above 0.85 in the low frequencies. For just a little more money, or perhaps the same price, a much better control might have been effected. A one point NRC is not believed to be a sufficient specification when selecting tile. However, listing SAC's for each octave band can also be awkward. A three point spectrum is introduced and used in the suggested specifications and guide given further on in this paper. These are listed as low frequencies (125, 250), medium frequencies (500, 1000), and high frequencies (2000, 4000). It is believed that this three point spectrum will generally eliminate the hazards of the single-numbered NRC rating, but not be so cumbersome or strict as listing SAC's for each octave band.

Economics

Too often false economy is practiced by selecting a less expensive tile and mounting with a consequence of poor results. More consideration should be given to the tile's effectiveness. The question should be asked whether a small amount of good tile would not be less costly and give better results than a large amount of cheaper, less effective tile. It should not be forgotten that labor, usually the big expense, costs the same whether installing a highly effective tile or a poor tile.

Practical Examples

Application of some of the above principles concerning the use of acoustical tile can best be illustrated by considering some typical examples which are common to many business and industrial operations. Many of these examples are the results of actual measurements taken at the National Reactor Testing Station and have been categorized to include a secretarial office, data process room, private office, hallway, bull pen, conference room, analytical laboratory, machine shop, and machine shop office. From the data contained in these examples, suggested specifications were developed and several are given in the Appendix. Such sample specifications were used in developing a general guide to be considered when writing specifications for actual use.

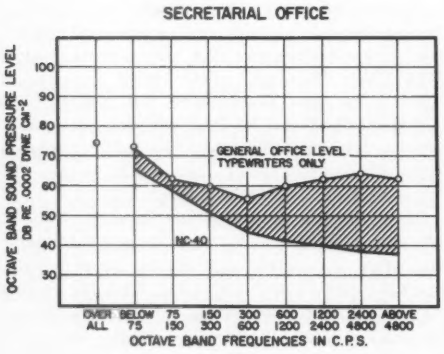

FIGURE 1.

The booklet, *Sound Absorption Coefficients of Architectural Acoustical Materials*, Bulletin XX, AIA No. 39-b, 1960, published by the Acoustical Materials Association, available for the sum of fifty cents, was used as a guide for determining SAC specifications.[11] This is an excellent reference for determining what materials the leading tile manufacturers produce and the effectiveness of these tiles. It should be noted that at least three manufacturers can meet the suggested specifications listed in each of the typical categories.

An NC-40 curve was chosen as the maximum desirable noise level in a secretarial office. The noise created from two typewriters in a typical office gave readings as indicated in Figure 1. The hatched area shows the region where absorption is desired. Based on this information and the SAC's from available literature of tile manufacturers, the following SAC's are suggested:

Low frequencies (125, 250) greater than 0.10
Medium frequencies (500, 1000) greater than 0.70
High frequencies (2000, 4000) greater than 0.85.

These SAC requirements, while high enough to effect a satisfactory correction are still low enough to allow a number 1 mounting and thus be farily economical.

Figure 2 gives noise levels as found in a data process room containing a number of sorters, key punches, summary punches, and similar equipment. An NC-50 curve was chosen for the data process room as not too much concentration is required. There, though, actual measurements showed that a more broad band type of noise at higher levels existed than was found in the secretarial office. Thus, greater absorption is necessary throughout the entire spectrum particularly at the low frequency end. As the required SAC's are fairly high, a number 7 mounting will probably be necessary to allow some of

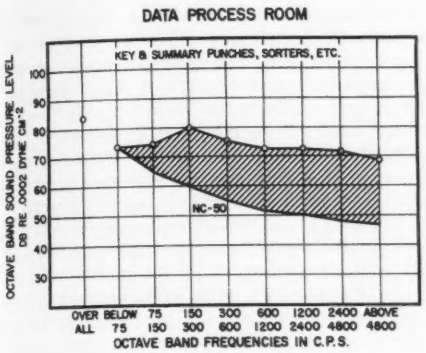

FIGURE 2.

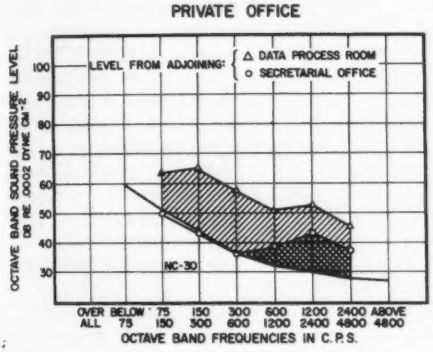

FIGURE 3.

the available tile to meet these specifications. Suggested minimum SAC's are as follows:

Low frequencies (125, 250) greater than 0.50

Medium frequencies (500, 1000) greater than 0.85

High frequencies (2000, 4000) greater than 0.85.

Figure 3 shows calculated noise levels originating in a data process room and a secretarial office as attenuated in two adjoining private offices by a typical wall construction and loose-fitting office door. Because of the greater concentration required in the private office, an NC-30 curve is suggested. The decrease in levels as compared to Figures 1 and 2 is due to the transmission loss through the wall and door. It is worth reiterating here that acoustical tile installed within the private office would be almost useless in abating noise generated outside the office. The correction must be applied in the source rooms. Application of the optimum correction in the source rooms which will meet the personnel requirements there will probably correct adequately the annoyance in the private office.

The noise levels found in a typical office building hallway are given in Figure 4. Here, again, the hallway noise level in the private offices adjoining the hallway is of more concern. Thus, the hallway noise should be reduced so that it will meet an NC-30 curve in the office after attenuation by typical doors and walls. To satisfy this problem, a number 7 mounting is suggested in the hall in order that the acoustical tile will meet the following SAC's:

Low frequencies (125, 250) greater than 0.40

Medium frequencies (500, 1000) greater than 0.90

High frequencies (1000, 2000) greater than 0.80.

Due to the high narrow shape of most halls, placement should probably be in the proportion of 40% on the ceiling and 60% on the walls, per unit length of hallway.

The bull pen type of office is one which is filled with a number of desks, such as an engineering or drafting room. In this type of office, conversations will be carried on at some desks while concentration is necessary at surrounding desks. In Figure 5, the shape of a typical NC-curve and a typical slope of the reverberation characteristics in an untreated room can be seen. Also, included is the shape of the speech energy spectrum, as averaged for both men and women.[12]

The frequency range of speech which communicates intelligence is approximately 600 cps and above and it is this region in which it is desirable to do most of the absorption. The treatment in this range will tend to reduce the intelligibility of a conversation to those nearby who are trying to concentrate. However, in the lower frequencies, less absorption is desirable, so

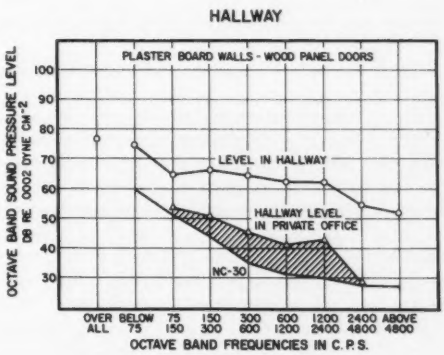

FIGURE 4.

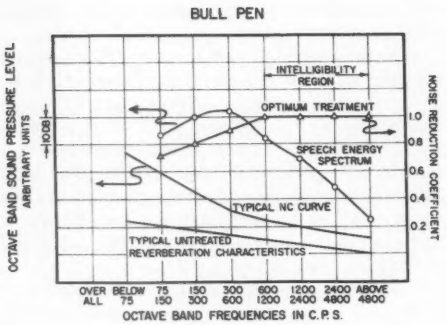

FIGURE 5.

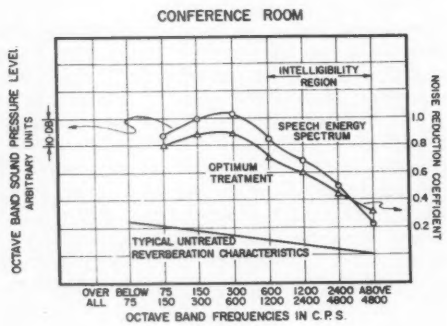

FIGURE 6.

that these unintelligible frequencies can help generate a "masking" condition to further remove distraction found in the intelligibility region. Because of less stringent requirements in the bull pen, specifications can be adjusted so that a number 1 or 2 mounting can be used. Suggested SAC's are:

Low frequencies (125, 250) equal to 0.20–0.40

Medium frequencies (500, 1000) greater than 0.80

High frequencies (2000, 4000) greater than 0.80.

In a conference room, exactly the opposite effect is desired in treatment as compared to the bull pen. Conversation is important and must be intelligible in all parts of the room. Therefore, maximum treatment is desired in the low frequency range to absorb as much of the unintelligible din as possible and remove its masking effect over the higher, intelligible frequencies. Thus, not much correction is desirable in the high frequency range; and, in fact, a low-frequency absorber with a hard surface for improved reflection is highly desirable.

Unfortunately, the acoustical tile now being produced does not give this type of correction. Other ways, such as panel absorbers, should definitely be considered here, particularly if the annoyance problem is severe. Acoustical tile should only be used as a "last resort" in this case. A number 7 mounting is the only type found that will allow the present-day tile to meet the recommended SAC's as given below:

Low frequencies (125, 250) greater than 0.65

Medium frequencies (500, 1000) equal to 0.75 plus/minus 0.10

High frequencies (2000, 4000) less than 0.55.

Much of the high level noise found in an analytical laboratory is from laboratory hoods and other ventilating equipment. Thought should be given to correction of the source before treatment with acoustical tile is considered. If tile is used, a fairly broad band coverage is necessary as can be seen in Figure 7. The desirable NC Curve to meet this requirement would depend on laboratory usage. For a laboratory where only routine analysis is being carried on, an NC-50 curve should be satisfactory. However, if research work is being done where a great deal of concentration is required in the laboratory, an NC-40 curve is recommended.

The suggested SAC's will probably restrict the tile installation to at least a number 7 mounting. Recommended SAC's are:

Low frequencies (125, 250) greater than 0.70

Medium frequencies (500, 1000) greater than 0.90

High frequencies (2000, 4000) greater than 0.90.

Machine shops generally do not require much concentration or conversation. However, the safety aspects of speech are important so that a spoken warning or direction can be easily understood. Because of this aspect, an NC-60

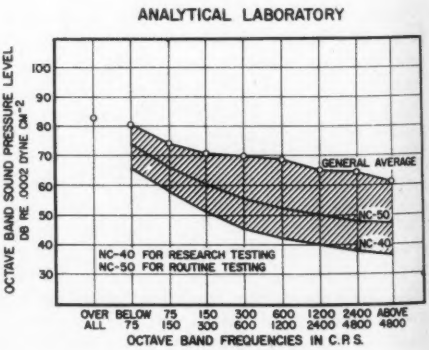

FIGURE 7.

curve is recommended. The levels shown in Figure 8 were taken in a high ceilinged, metal-working shop. The occasional high levels occurred during stainless steel reaming operations. In general, a fairly broad band coverage is required in this type of shop. The same SAC's and mounting are suggested here as were suggested for the analytical laboratories.

Figure 9 shows the machine shop noise as it is measured in an adjoining office. Transmission losses through a metal and glass partition and door account for the reduction of the noise levels. Because of greater concentration requirements in the office than in the shop, an NC-40 curve was chosen. The transmission loss brought the general average below an NC-40, but some correction is required in the shop (not in the office) to reduce the occasional high levels.

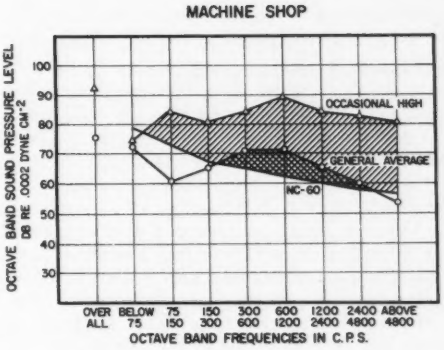

FIGURE 8.

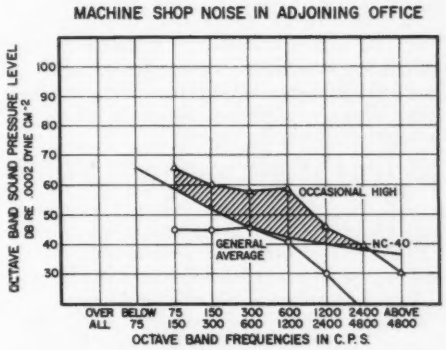

FIGURE 9.

Other Requirements

Noise reduction values are not the only considerations necessary when selecting or specifying acoustical tile. Both the fire protection engineer and illumination engineer will have requirements concerning flame resistance and light reflection, respectively. The room occupants will also be concerned with aesthetic appeal. Painting the material without appreciable lowering the SAC's may be an important factor. Placement and possibly structural requirements are other factors to consider.

Flame Resistant Properties

The fire hazard classification of acoustical materials is one of the more important considerations in the specifications. Introduction of a combustible material into a building with a good fire resistance rating can severely lower the safety features and may affect insurance rates. Federal buildings usually require a Class A material as defined in part 3.7.1 of Federal Specification SS-A-118B.[13] This requires that no flames issue from the material under certain required flame tests. Care, also, should be taken to see that a noncombustible acoustical material is not backed by a combustible material, such as asphalt paper.

The booklet, *Sound Absorption Coefficients of Architectural Acoustical Materials*,[14] lists the flame resistance classification of most of the manufactured tiles. The Building Materials List by Underwriter's Laboratories, Inc.[15] gives the fire hazard ratings of materials submitted to them for testing and labeling services.

Light Reflection

Light reflection values of the tile can be important to the illumination engineer, both in a building design or in the addition of tile to an existing room. Light reflection is used when calculating the illumination of a room, so a poorly reflecting tile could raise the light fixture costs of a new building or possibly lower the lighting in an existing room to an undesirable point. Although the possibility is remote, an undesirable glare could also be produced from a high reflective surface. Some light reflection values are listed in Bulletin XX[16] by the Acoustical Materials Association. The manufacturer can furnish additional information, if needed.

Paintability

Where cleaning costs are prohibitive, it may be necessary to occasionally paint the tile. Some tile will greatly lose its effectiveness when painted, so a restrictive provision may have to be included in the specifications. Federal Specification SS-A-118B[17] gives painting requirements which probably will satisfy most cases.

Aesthetics

While the appearance of a tile may not be important in a machine shop, it does have to fit into the decor of an office. It should be specified that the material must fit into the room decor so that the low bidder does not erect sheets of batting in an executive suite.

Structural Requirements

Although today's buildings would almost always support most acoustical materials being produced, rare instances may occur in which the weight and/or size may have to be mentioned in the specifications. This information, if needed, may be found in Bulletin XX by the Acoustical Materials Association.[18]

Guide for Suggested Specifications

A specifications guide has been developed which takes into account the requirements discussed in some detail above. Sample applications of this guide are given in the Appendix, where suggested specifications are listed for the examples mentioned previously.

GUIDE FOR SPECIFICATIONS FOR USE OF ACOUSTICAL TILE

A. Flame Resistant Properties.
B. Noise Reduction Characteristics.
   1. Sound Absorption Coefficients at:
      Low frequencies (125, 250 CPS)
      Medium frequencies (500, 1000 CPS)
      High frequencies (2000, 4000 CPS)
   2. Placement
   3. Mounting (suggested)
C. Light Reflection.
D. Paintability
E. Aesthetics
(Structural, if necessary)

Conclusions

A suggested guide has been presented which should give more satisfactory results than do the specifications which many industries are using to date. Applications of this guide are illustrated with examples which are common to many industrial plants and business facilities.

It should again be pointed out, though, that tile is not a cure-all and should only be used after the situation has been evaluated and it is found that the noise problem could not be corrected at the source or isolated. Other types of environmental correction which might be more effective and cheaper should also be investigated. These would include such devices as panel absorbers, functional absorbers, and artificial masking techniques for correction of a noise environment.

If tile is selected for the correction, spectrum shape, placement and mounting must be considered in order to achieve the maximum correction at the minimum cost.

Finally, it must be noted that this guide is not intended as a solution to all annoyance noise problems. It is only intended to help obtain more satisfactory usage of money to be spent on acoustical tile. Many noise problems occur which only a trained acoustician can solve satisfactorily. An acoustical consultant usually charges approximately $18 to $25 per hour and in two or three hours could often save the cost of his fee many-fold, plus, giving the assurance of satisfactory results.

Acknowledgment

The author wishes to make grateful acknowledgment to Mr. George Brockett of Idaho Falls, Idaho, for the great amount of time and high degree of technical knowledge he voluntarily contributed to the preparation of this paper. Without his assistance, the report could not approach its present coverage of the subject.

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17. *Ob. Cit.*, U. S. Government Printing Office.
18. *Ob. Cit.*, Acoustical Materials Association.

Appendix

Acoustical Tile Specifications for Data Process Rooms

A. Fire Resistance
   The material shall have a flame resistance equal to or better than a Class A material

as defined in part 3.7.1 in Federal Specification SS-A-118B.

B. Noise Reduction Characteristics

1. Sound absorption coefficients

The material shall have the following sound absorption coefficients:

Low frequencies (125, 250)—0.50
Medium frequencies (500, 1000)—0.85
High frequencies (2000, 4000)—0.85

2. Placement

The majority of the treatment shall be on the ceiling. Distribution should allow for approximately 80% or more of the ceiling area to be covered and at least 20% of the wall area. Opposing walls shall have approximately equal amounts.

3. Mountings

Mounting shall be the most economical which will satisfy or improve the required SAC's.

Suggested Mounting—number 7 as defined by the Acoustical Materials Association.

C. Light Reflection

The exposed area of the treatment shall have a minimum light reflection value of 0.75. Furthermore, it shall not produce an annoying glare.

D. Paintability

Material shall meet paintability requirements as defined in part 3.6 in Federal Specification SS-A-118B.

E. Aesthetics

The material shall have an exposed surface which when mounted will meet with the general decor of the room in which it is to be used.

Acoustical Tile Specifications for Machine Shop

A. Fire Resistance

The material shall have a flame resistance equal to or better than a Class A material as defined in part 3.7.1 in Federal Specification SS-A-118B.

B. Noise Reduction

1. Sound absorption coefficients

The material shall have the following sound absorption coefficients:

Low frequencies (125, 250)—0.70
Medium frequencies (500, 1000)—0.90
High frequencies (2000, 4000)—0.90

2. Placement

Distribution of treatment should allow for approximately 75% or more of the ceiling area to be covered and at least 25% of the free wall area. Opposing walls shall have approximately equal amounts.

3. Mountings

Mounting shall be the most economical which will meet the required SAC's. Suggested Mounting—number 7 as defined by the Acoustical Materials Association.

C. Light Reflection

The exposed area of the treatment shall have a minimum light reflection value of 0.75. Furthermore, it shall not produce an annoying glare.

D. Paintability

Material shall meet paintability requirements as defined in part 3.6 in Federal Specification SS-A-118B.

E. Aesthetics

The material shall have an exposed surface which when mounted will meet with the general decor of the room in which it is to be used.

Determination of Trichloroethylene in Air

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The sensitivity and accuracy of determination of trichloroethylene using the Fujiwara pyridine-alkali reaction has been improved. The procedure, as outlined, will detect one microgram of trichloroethylene in the aliquot analyzed and concentrations as low as one part per million by volume can be determined. The reproducibility of the method was found to be better than one-half of a microgram of trichloroethylene over the range of zero to 100 micrograms.

THE commercial production and use of trichloroethylene requires that a suitable method of analysis be available to the industrial hygienist. A determination capable of measurement of low concentrations of trichloroethylene in air is necessary to adequately serve as a means of safeguarding the health of workers exposed to this compound.

Several workers have established the methodology for determination of trichlorethylene in water, air and wastes. The procedure discussed herein is based on the Fujiwara pyridine-alkali reaction. The determination requires quantitative extraction of trichloroethylene from an air sample by use of toluene. The toluene extract is then reacted with pyridine and potassium hydroxide. After the necessary reaction time, water is added for color development which is read at 537 mμ. The procedure, as described, will detect one microgram of trichloroethylene in the aliquot analyzed and can be used to determine trichloroethylene concentrations in air as low as one part per million by volume using a 250 ml air sample.

Sampling Procedure

A 250-ml gas sampling tube is evacuated and employed for collection of air samples. Kel-F grease or a similar non-hydrocarbon type stopcock grease should be used to prevent leakage.

The sampling tube is opened to the atmosphere at the desired location and allowed to fill with air. The sample is then returned to the laboratory for analysis. The air temperature should be recorded at the time of sample collection.

Sample Preparation

Cool the gas sampling tube by placing it in an ice-water bath. After sufficient chilling, add 2 ml of toluene to sampling tube by means of a suitable delivery funnel and maintain partial vacuum in the tube. Shake the tube vigorously to coat the walls with toluene. Allow sampling tube to warm to room temperature. Vent tube to establish atmospheric pressure within the tube. Shake the tube well to establish equilibrium distribution between liquid and gas phases and record the temperature. Drain the toluene from sampling tube into a 10-ml graduated cylinder. Recovery of the 2-ml toluene volume should be approximately 1.8 ml. Allow any water droplets to separate from the toluene layer.

Reagents

Toluene: reagent grade.

Dry pyridine: This reagent must be low in water content. This is insured by pasteurization. Any water in the sample of pyridine is removed as the pyridine-water azeotrope by distillation.

1% Ethanolic potassium hydroxide: Dissolve 1.0 gm of potassium hydroxide in 95% ethyl alcohol and dilute to 100 ml with ethyl alcohol.

Methanol: reagent grade, (relatively dry). This reagent should be relatively dry since its major purpose is to establish co-solubility of the organics and water present in the reaction mixture.

Standard trichloroethylene solution: Add approximately 60 mg of trichloroethylene ($CHCl:CCl_2$) to 100 ml of toluene. An aliquot of this solution may then be diluted further with toluene to obtain concentrations for calibration purposes.

Procedure

Transfer one ml of toluene (or an aliquot diluted to one ml with toluene) to a 25-ml glass-stoppered graduated cylinder. Extreme care must be taken not to transfer any water that may be present. Add 5 ml of dry pyridine and 0.35 ml of 1% ethanolic potassium hydroxide. Mix well by shaking and allow solution to stand

for exactly five minutes. Then add one ml of distilled water, mix well and allow solution to stand in the dark for fifteen minutes. After this elapsed time, immediately add 3 ml of methanol and measure the optical density at 537 mμ exactly thirty seconds after methanol addition.

Calibration Curve

It is necessary to prepare a calibration curve on the day of analysis because of sensitivity of the method to water in the reagents. This is accomplished by preparing known dilutions of trichloroethylene in toluene and developing the color by the procedure described. Plot optical density versus micrograms of trichloroethylene. Calibration is practical in the range of zero to 100 micrograms of trichloroethylene.

Calculation

The concentration as ppm by volume of trichloroethylene vapor in air may be calculated by the following equation when a 250-ml gas sampling tube is used:

$$\text{ppm trichloroethylene} = 2.26 \times 10^{-3} \gamma FT$$

where:

γ is expressed in micrograms of trichloroethylene as found from the calibration curve,

F is the distribution equilibrum factor as found from figure 1, and

T is the sampling temperature in degrees Kelvin.

and 2.26×10^{-3} is a constant for a 250-ml sampling tube derived from

$$\frac{22{,}400}{277 \times 273 \times 131}$$

where:

22,400 is milliliters per gram-mole,

277 is the approximate volume of the nominal 250-ml tube,

273 is the temperature at standard conditions, degrees Kelvin, and

131 is grams of trichloroethylene per gram-mole.

Discussion

To insure reliable results, gas sampling tube evacuation must be carefully carried out. If evacuation is poor, the pressure factor must then be included in calculation since incomplete evacuation has a direct effect on the quantity of air sampled and thus, on concentration of trichloroethylene in the sample tube.

The venting procedure to establish equilibrium distribution between liquid and gaseous phases is a very necessary step in the procedure since without this equilibrium, results cannot be

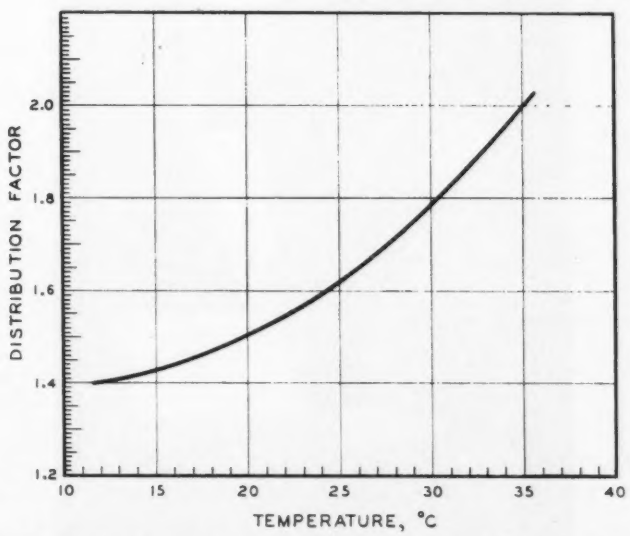

FIGURE 1. Distribution factors for trichloroethylene in air. Data are based on use of 2 ml toluene and a 277-ml sample of air.

calculated to concentration in the original sample.

The greatest source of potential interference in the determination is introduction of water to the reaction at any time prior to that specifically called for in the procedure. For this reason, there are several precautions which must be observed. The pyridine should be pasteurized to remove any water that may be present, and the ethanolic potassium hydroxide should be protected from moisture. The methanol should also be relatively dry.

The color development is light sensitive. Hence, after addition of water, samples should be held in the dark for 15 minutes. After addition of methanol, the color intensity decreases slowly. For this reason, reading of optical density after a specific time interval is suggested.

When all precautions are properly applied, results obtainable with the procedure are reproducible to less than one-half of a microgram of trichloroethylene over the range of the test. The following compounds will not interfere with the determination: chloroform, carbon tetrachloride, trichloroethanol, chloral hydrate, urochloralic acid and trichloroacetic acid according to Seto *et al.*[1]

Reference

1. Seto, T. A., and M. O. Schultze: Determination of Trichloroethylene, Trichloroacetic Acid and Trichloroethanol in Urine. *Anal. Chem. 28:* 1625 (1956).

Hands Across the Sea

DR. ETHEL BROWNING (left) of London, England, receives from Mr. Jack Radcliffe the certificate of award of honary membership in the American Industrial Hygiene Association. This honor was presented in recognition of the many contributions to the profession of industrial hygiene over her long years of service in this field. The award was made on the occasion of the annual American Industrial Hygiene Association banquet at the American Industrial Hygiene Conference in Detroit, Michigan.

Air Pollution as Determined by Corrosion Rates in Test Materials

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Oklahoma State Health Department, Oklahoma City, Oklahoma, and
Robert A. Taft Sanitary Engineering Center, U. S.
Public Health Service, Cincinnati, Ohio

Inexpensive iron discs exposed to the atmosphere for several weeks will undergo weight changes as a result of the corrosive effects of atmospheric pollutants. These changes are easily measured as an indication of the degree of such pollution. While the procedure does not allow for identification of pollutant species, it does provide a simple, inexpensive screening technique for the evaluation of specific emissions or the study of relative trends in communities. Field tests by this method are described.

DAMAGE to paint, gutters, and window screens has been observed in certain areas of Tulsa, Oklahoma and was believed to be due to corrosive contaminants in air. The City and State Health Departments conducted the study described herein to determine the relative severity of corrosion in different areas.

Test Method

Wafer shaped wrought iron discs were used as the principle test device. These discs were cut from S.A.E. 1095 flat bar stock. The resultant discs were approximately 50 mm in diameter and 3 mm thick. Each disc weighed approximately 60 grams. Care was taken in cutting discs to insure that no strains were put in the metal, for this could produce unusual corrosion rates in the discs.

Discs were cleaned in 10 per cent sulfuric acid for about six minutes initially, and at the end of each exposure period they were again cleaned in sufuric acid until the rust coating was dissolved away. Following the acid treatment they were washed in water, and in some instances residual rust removed with a scouring powder, washed, dried and then weighed on an analytical balance. They were then wrapped separately in squares of white vegetable parchment paper for transport to the exposure station. Discs were handled with tongs in the laboratory and subsequently handled with the paper wrapping to minimize contact with the hands and contaminating body oils. Within a day or two of their preparation, these discs were taken to 21 field test sites in and around Tulsa and mounted on small wooden stands about five feet above ground level (Figure 1). Discs were mounted vertically, and wooden holders were constructed so as to cover only a minimum area at two points on the disc. Stands were not protected from the weather, and consequently the discs were exposed to the same elements to which any outdoor metal surface would be exposed.

Two discs were exposed in an upright position at each sampling point. One was oriented in a north-south direction, and the second was oriented in an east-west direction. This was done to determine whether or not orientation with respect to sunlight or with respect to prevailing winds might have some effect on corrosion rates. No systematic difference was noted between the two orientations and the variation between any two samples averaged about 5 per cent. This was considered to be due to sampling error inherent in the method. Consequently, the average of these two samples was used in reporting results. After samples had been exposed for periods varying from 8 to 12 weeks, they were returned to the laboratory where they were again dried and weighed.

In long term corrosion studies the effect of corrosion is usually noted as a loss of material. This may be reported as a loss in thickness, weight, or change in an attribute such as tensile strength of the material. For relatively short term exposures as used in this study, the corrosion effects are recorded as a weight gain. This is accounted for by the additional weight of the combining elements which form rust on the iron discs. An example of this might be:

$$4\,Fe + 3\,O_2 \rightarrow 2\,Fe_2O_3$$

* Presently with the U. S. Public Health Service, Region VII, Dallas, Texas.

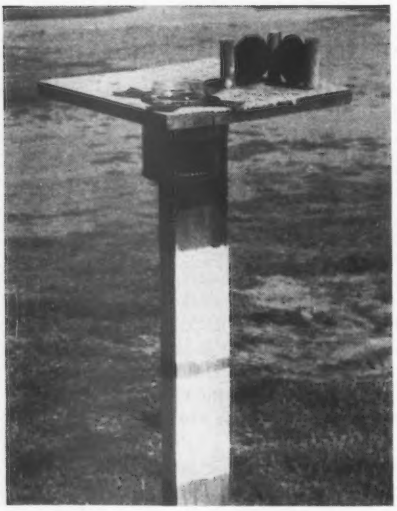

FIGURE 1. Test site showing corrosion test discs, dustfall jar, and paint test strips. Results of the latter two series of tests are not covered in this report. (Photograph through courtesy of Oklahoma City-County Health Department.

TABLE I

Duration of Exposure Compared With Corrosion Rate

Dates of Exposure (1958)	Duration (days)	Weight Gain (mg)	Rate of Wt. Gain (mg/day)
I. Area of high corrosion (Sample Site B)			
3/27 to 4/3	7	40.1	5.7
3/27 to 4/16	21	143.2	6.8
3/27 to 5/8	42	468.0	11.2
3/26 to 6/2	68	603.0	8.9
			avg. = 8.1
II. Area of low corrosion (Sample Site W)			
3/27 to 4/3	7	10.0	1.4
3/27 to 4/16	21	37.6	1.8
3/27 to 5/8	42	80.3	1.9
3/26 to 6/2	68	111.0	1.6
			avg. = 1.7

TABLE II

Corrosion Rates at 21 Sampling Sites

(Weight gains are reported in milligrams/day)

Site	Test Period					Avg. Wt. Gain for 5 Periods
	7/22–10/21/57 (91 Days)	1/6–3/10/58 (63 Days)	3/26–6/2/58 (68 Days)	7/1–9/2/58 (63 Days)	9/9–12/4/58 (86 Days)	
A—6730 W. 25th St.	2.55	1.76	2.02	1.82	1.30	1.89
B—4900 W. 21st St.	8.11	5.75	8.86	6.31	5.34	6.88
C—3435 W. 21st St.	2.88	2.31	2.32	1.79	—	2.32
D—16th & Tacoma	4.30	4.12	3.06	—	—	3.83
E—West edge of Arkansas River at 22d St. N. of West Edge of 21st St.	3.44	3.98	3.38	4.40	3.67	3.78
F—2500 S. Maybell	4.26	5.19	5.68	2.45	2.13	3.94
G—46th & Elwood	2.91	3.24	3.35	1.72	1.10	2.46
H—Approx. 4900 W. 49th	2.18	2.18	2.38	1.89	1.68	2.06
I—6800 S. Union	2.78	2.34	2.23	—	—	2.42
J—73rd W. & 15th St.	2.34	1.82	2.17	2.38	1.18	1.98
K—61st W. & 13th	4.01	2.50	2.89	2.77	1.52	2.74
L—33rd W. & Sand Springs Rd.	3.14	2.74	2.99	2.91	1.56	2.67
N—27th & Riverside	3.10	2.49	2.35	0.89	1.31	2.03
O—3939 S. Trenton	1.91	1.62	1.07	1.03	0.58	1.24
P—616 S. Boston	2.21	—	1.78	0.87	1.87	1.68
R—600 S. College	—	1.38	1.45	1.12	0.92	1.22
S—Harvard & Apache	2.46	2.07	2.12	2.31	1.54	2.10
T—N.E. of City in Mohawk Park	2.03	1.42	1.19	1.47	0.59	1.34
U—Edison & S. 49th W.	3.38	2.08	—	2.61	—	2.69
V—1100 Blk S. 49th W.	4.10	2.68	3.22	3.50	—	3.38
W—4616 E. 15th St.	—	—	1.64	1.45	1.11	1.40
Avg. 21 Sites	3.27	2.71	2.81	2.30	1.71	2.57

In this case the weight gain would be accounted for by the oxygen atoms forming the rust.

The rate of weight gain due to corrosion depends on a number of factors. At some point in the corrosion process rust particles flake off, reducing the weight gain. For extended exposure this results in a weight loss. Corrosion rates could be reduced if the rust were to form a protective coating on the surface. Conversely, a rust coating may retain moisture longer than a smooth surface, which would tend to increase the corrosion rate. Pitting of the surface due to corrosion could increase the surface available for additional corrosion.

The net effect of these variables was evaluated by a test designed to show how the corrosion rate, as indicated by daily weight gain, would vary for exposures over different time periods (Table I). In order to reduce as much as possible the effects of varying exposure conditions for these tests, the starting time was practically the same for all tests. Two of the sampling sites were chosen for these tests, one in an area with high corrosion rates and one in an area with low corrosion rates. It can be seen that at both sampling sites the rate of gain increased steadily as the duration of exposure was increased up to 42 days. This may be due to the increase in surface created by pitting and the possible retention of moisture on the surface. By 68 days of exposure the rate of weight gain had begun to decrease, probably due to sloughing off of cor-

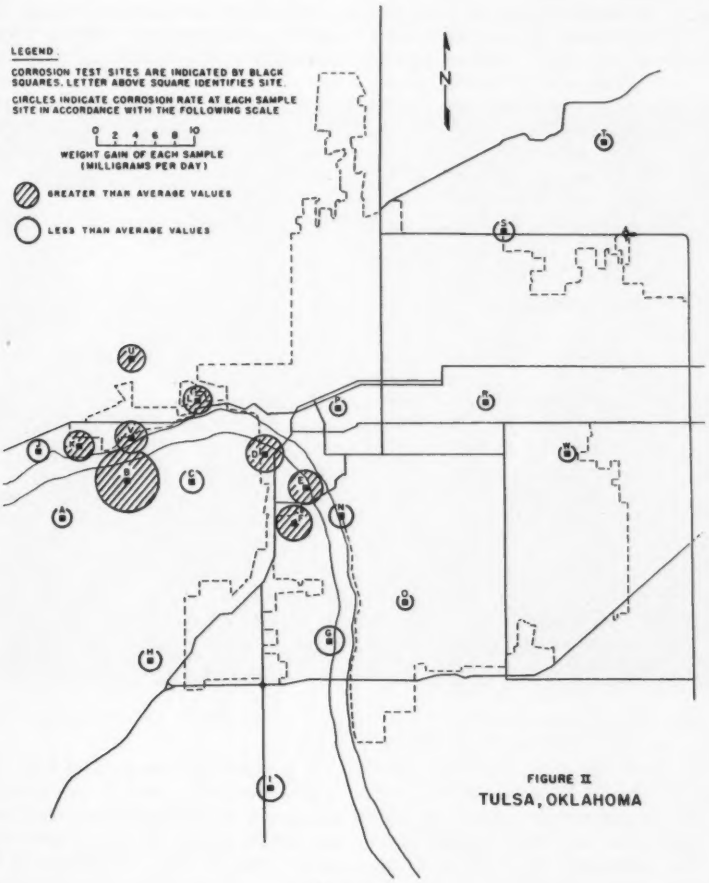
LEGEND
CORROSION TEST SITES ARE INDICATED BY BLACK SQUARES. LETTER ABOVE SQUARE IDENTIFIES SITE.
CIRCLES INDICATE CORROSION RATE AT EACH SAMPLE SITE IN ACCORDANCE WITH THE FOLLOWING SCALE
0 2 4 6 8 10
WEIGHT GAIN OF EACH SAMPLE (MILLIGRAMS PER DAY)
GREATER THAN AVERAGE VALUES
LESS THAN AVERAGE VALUES
N
FIGURE II
TULSA, OKLAHOMA

FIGURE 2.

rosion products, and at this time it was close to the average weight gain for the entire period. Additional testing is required to determine the change in weight gain which will occur over even longer exposure periods.

Results of Study

Tests were conducted during five separate periods between August, 1957 and December, 1958, and results of the field work were tabulated (Table II). The average corrosion rate for all 21 sampling sites and all five sampling periods was found to be 2.57 milligrams of weight gain per sample per day. The five highest values were found at sites B, D, E, F, and V. These values ranged from 1.3 to 2.7 times the average for all samples. These sites are in the western portion of Tulsa along the Arkansas River, and with the exception of site V, they are in an industrial area which includes two oil refineries, two fertilizer manufacturing plants, and a sulfuric acid production plant (Figure 2). Site V is in a residential area immediately north of the other four high corrosion sites, but is in the direction of prevailing winds from the industrial area.[1]

The five lowest corrosion rates were found at sites O, P, R, T, and W. These values ranged from 0.48 to 0.65 times the average for all values. These sites are scattered throughout the Tulsa area. They are located in either park, residential, or shopping areas, and are not near substantial air pollution sources.

The above results were based on the average corrosion rates found during all five test periods. The relative corrosion standing of any one test site was consistent for all test periods. For example, site B showed the highest results during all tests, and sites O, P, and R showed consistently low results, with site O having the lowest individual results on three of the five tests.

This appraisal technique could be used for following corrosion trends over relatively long periods of time, but in order to do this it would be desirable to expose samples for uniform time periods and over comparable seasons of the year. Since these tests were conducted for varying time periods, and over a period of only slightly more than one year, rigorous trend analysis cannot be made. It would appear, however, based on average corrosion rates for each test period, that there is a trend toward lower corrosion rates. Additional tests would be required to confirm this possibility.

Discussion

Acid gases which play a significant part in corrosion are given off during many combustion processes. In the majority of metropolitan areas the most important of these gases is sulfur dioxide. Coal, gas, and petroleum fuels contain varying amounts of sulfur. When these fuels are burned, most of the sulfur passes to the atmosphere as sulfur dioxide or sulfur trioxide, the latter forming sulfuric acid upon contact with moisture in the air. The acid thus formed may be washed from the atmosphere by rain, removed from the air upon being absorbed or adsorbed by dust or soot, or become attached to surfaces. Thus, exposed materials are subjected to acid rains and to direct contact with corrosive aerosols.[2]

Salts such as ammonium sulfate and sodium chloride are corrosive. Although they are most abundant in marine atmosphere, they also exist in man-polluted atmospheres. These salts hydrolyze in water to form sulfuric and hydrochloric acid, which have marked corrosive action. Even though alkalies are among the less common pollutants of urban and industrial atmospheres, they should be considered in evaluating corrosion problems of a community.

Summary

Some of the corrosive effects of atmospheric pollutants may be evaluated by means of a relatively simple test based on the weight gain that occurs when an iron disc is exposed to the atmosphere for a few weeks. The weight gain is due to the formation of corrosion products on the surface of the test material. Field tests are easily performed, and a minimum of laboratory equipment is required for analysis of samples. Consequently, this furnishes an inexpensive method to determine relative corrosion rates in different areas of a community, as well as trends in corrosion rates over a period of years. The method does not allow for identification of pollutant species. Consequently, it should be considered as a screening technique to be used in connection with evaluation of specific emissions and atmospheric concentrations of corrosive agents.

A field test of this method was conducted in Tulsa, Oklahoma, and a substantial variation was found in atmospheric corrosiveness in different places within the city. Corrosion as measured by this method was greatest in the western portion of Tulsa along the Arkansas River.

Acknowledgments

The authors wish to acknowledge Dr. T. Paul Haney, Director; Mr. Clyde B. Eller, Sanitation Director; Mr. Homer R. Spencer, Laboratory Director, of the Tulsa City-County Health Department for their substantial contributions in the conduct of this study.

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1. U. S. Department of Commerce, Weather Bureau: *Local Climatological Data, Tulsa, Oklahoma.* U. S. Department of Commerce, Washington, D. C.
2. Greenburg, L., and M. B. Jacobs: Corrosion Aspects of Air Pollution. Presented at the Northeast Regional Meeting of the National Association of Corrosion Engrs. (May 1955).

THE NEW AND THE OLD

MR. WILLIS G. HAZARD (left) incoming President of the American Industrial Hygiene Association for the next year presents to Mr. Jack Radcliffe, the retiring President, the Association's plaque in recognition of the fine service and leadership which Mr. Radcliffe provided during his term of office.

Air-Borne Particulate Beta Radioactivity Measurements of the National Air Sampling Network—1953–1959

L. R. SETTER, C. E. ZIMMER, D. S. LICKING, and E. C. TABOR

Robert A. Taft Sanitary Engineering Center, U. S. Public Health Service, Cincinnati 26, Ohio

The air-borne particulate radioactivity data of the National Air Sampling Network have been summarized for the period October, 1953, through December, 1959. Sampling and counting procedures are described, and the decay rates of fission products are considered. Radioactivity of particulates is presented relative to source and distribution.

THE U. S. Public Health Service started a survey of air-borne particulate pollution of urban and nonurban areas in October, 1953. The principal objectives of the National Air Sampling Network were to develop adequate sample collecting procedures and to determine amounts of specific organic and inorganic pollutants, including nuclear bomb debris. High-volume samplers and glass fiber filters were furnished interested state and municipal agencies, and by the end of 1953, samples were being collected at twenty stations. The Network, reorganized January 1, 1957, now includes approximately 185 urban and 51 nonurban stations in the 50 states, Puerto Rico and the District of Columbia. Nonurban stations sample every year and urban stations sample on an annual or biennial basis, with at least one city in each state sampling every year. In any one year sampling will be conducted at approximately 135 urban and 40 nonurban stations (Figure 1). At each station one 24-hour sample is collected in each two-week period on a randomized sampling schedule. During 1957–1959 sampling was continuous at Atlanta, Birmingham, Cincinnati, Detroit, Los Angeles, New Orleans, Philadelphia, and San Francisco.

Most samples collected in 1953 and 1954 were tested for gross beta and gross alpha radioactivity, whereas only the samples from approximately a dozen selected stations were tested for beta activity between January, 1955 and May, 1957. Since May, 1957, measurements have been made on all samples received.

It is the purpose of this paper to present a summary of the results of radioactivity measurements for the period 1953 through 1959.

Presented at the Twenty-first Annual Meeting of the AIHA, Rochester, New York, April 28, 1960.

Collection of Samples

Air-borne particulate samples are obtained with a high volume air sampler operated for 24 hours using an 8- x 10-inch glass fiber filter capable of removing practically 100 per cent of all particulates 0.3 micron, or greater, in diameter. At nonurban stations air flow rates average about 55–65 cubic feet per minute. Since the air flow progressively diminishes as accumulating particulates cause an increase in the flow resistance of the filter, the average sampling rates at most urban stations are in the range 40–50 cfm. The volume of air filtered, taken as the product of the sampling time and the average of initial and final flow rates, usually averages 2000–2500 cubic meters.

From October, 1953, through December, 1956, the samplers were placed in recommended shelters with the filters in a vertical plane. Standard shelters were provided beginning January 1, 1957 which placed the filter in a horizontal plane three feet above the ground or roof location.

Following collection of the sample, the filter placed on a manila folder, is folded lengthwise to form a sandwich with the particulate matter inside. With a copy of sampling and weather data, the sample is sealed in an envelope and mailed to the Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio. Upon receipt, the samples are equilibrated overnight at 75°F and 50 per cent relative humidity, weighed, and counted directly for radioactivity.

Radioactivity Measurements

Filter Swatch Counting: From October, 1953 to May, 1957, alpha and gross beta-gamma measurements were made by counting a 45 mm

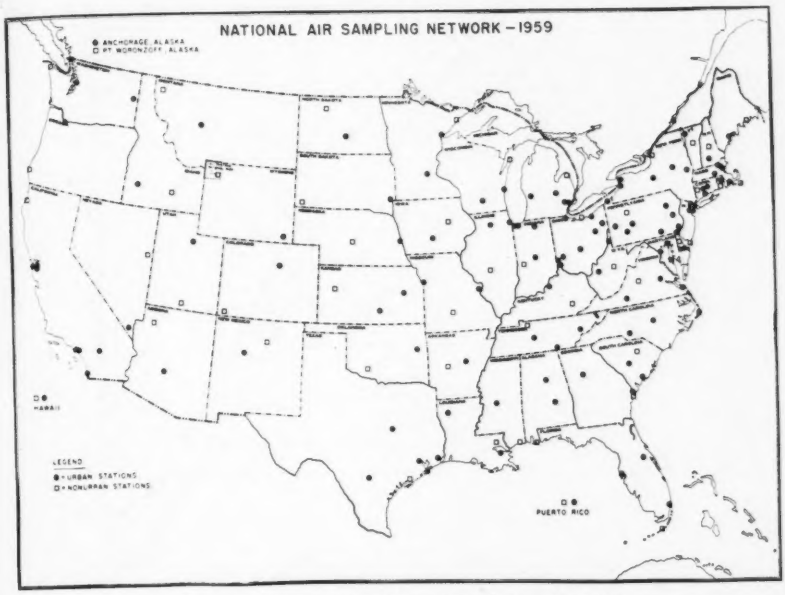


FIGURE 1. National Air Sampling Network, 1959.

diameter swatch from each filter in an internal proportional counter. The swatch, punched at random from the filter, was placed in an aluminum counting dish and wetted with conducting fluid (Anstac M, Chemical Development Corp.) After drying overnight, the sample was counted for two four-to-eight-minute periods at both alpha and beta plateaus.[2, 3] The activity, corrected for instrument geometry, backscatter, self-absorption, and decay was reported in picocuries (10^{-12} curies) per cubic meter (pc/m^3) of air as of the date the sample was removed from the sampler.

The more active samples were counted several times for decay and the results, plotted on log-log paper, were extrapolated to time of collection. With judicious choice of the date of formation (most often corresponding to known test dates reported in the newspapers), a negative exponential slope of 1.2 usually defined the decay of samples collected in 1953 and 1954. This same slope was obtained for the more active samples collected since that time, but a slope of 1.0 was found more applicable for intermediate air activity ten or more days in age. Sometimes the data clearly indicated a mixture of young and old fission products. The method of extrapolation for samples of young fission products is subject to considerable uncertainty when the time lapse between sample collection and counting is over three or four days.

Whole Sample Counting: Beginning May, 1957, gross beta activity was measured by placing the entire filter sample beneath a 7.5 inch diameter thin-window (Mylar) proportional gas-flow counter (NMC-PCC12).[4] The beta activity was measured two to four days after collection; and again four to six days later to permit extrapolation of activity to the date of collection and to establish the decay rate.

Decay Rate of Fission Products

The fission of U-235 yields elements of atomic numbers between 85 and 150. Many of these elements are beta-gamma emitting radionuclides, each with a specific decay rate and spectrum of beta energies. Calculations by Bolles and Ballou[5] from data on the abundance of radionuclides indicate that when the logarithm of radioactivity is plotted against the logarithm of the age of fission product, the best fit straight line decay rate will have a negative slope of 1.2. Figures 2, 3 and 4 show typical decay rates obtained on some of the more active air-borne particulate samples since 1955.

Curve A, Figure 2 is a line of negative slope 1.2 describing the decay of a sample collected on March 2 from a U. S. Continental test of March 1, 1955. It is noted that the first observation was made when the bomb debris was seven days old and that, with few exceptions, the observed values fall very near to this general decay slope.

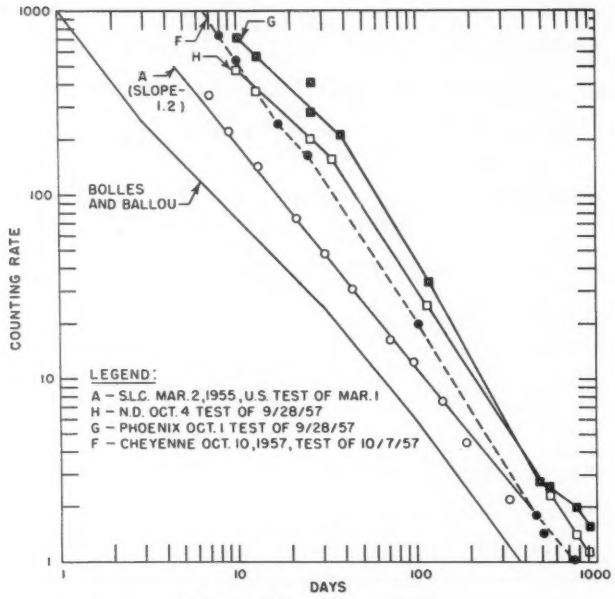


FIGURE 2. Beta decay rates.

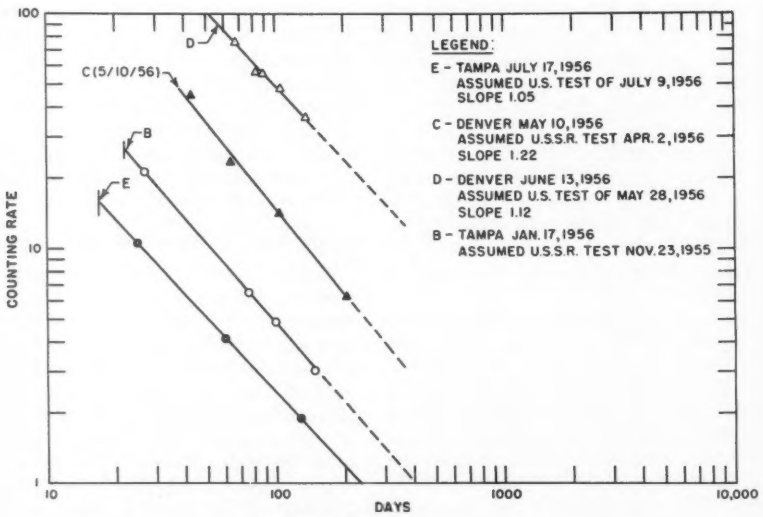


FIGURE 3. Beta decay rates.

The theoretical Bolles and Ballou decay data are plotted for comparison. It is noted in particular that the negative decay slope at age 100 to 1000 days tends to be greater than 1.2 for both the theoretical data and the observation points for Curve A. Curves G and H, Figure 2, show decay data of bomb debris with estimated formation date of September 28, and Curve F, that of October 7, 1957. These decay rates are greater than the 1.2 factor, which may be due to (a) samples which are not representative of mixed fission product, (b) a deviation in the abundance

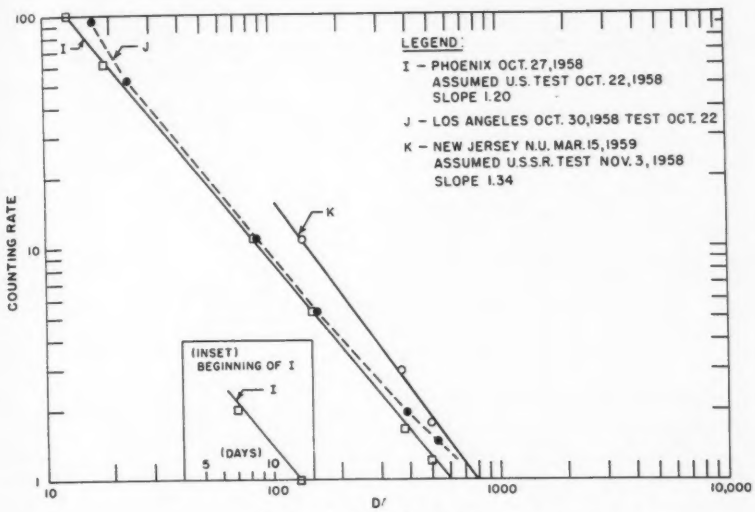


FIGURE 4. Beta decay rates.

of radionuclides from the theoretical in the Bolles and Ballou calculations, (c) the possible presence of tracer elements, and (d) a lack of acounting for fractional parts of a day.

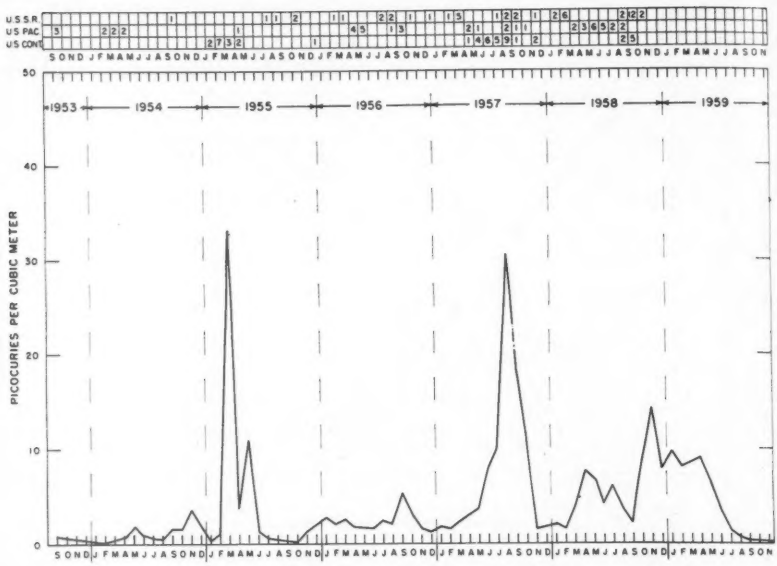
Curve B, Figure 3 shows a decay rate of 1.12 for a sample collected on January 17, 1956, from a USSR test reported on November 23, 1955. The bomb debris was estimated to be 32 days old when first counted. If the test had been made on November 19, 1955, the decay slope would have been 1.2. Curve C, Figure 3 shows air-borne activity on a May 10, 1956 sample, presumably originating from a USSR test of about April 2, 1956, whereas Curves D and E represent the activity of debris, assumed to be from U.S. Continental tests of May 28 and July 9, 1956.

Curves I and J, Figure 4 show decay data for samples collected in October, 1958, from California and New Mexico in which the bomb debris appears to be of recent origin, presumably from a test on October 22, 1958. Finally, Curve K shows a decay slope of 1.34 for a New Jersey sample collected March 15, 1959, which was presumed to originate from the last reported test in 1958 (USSR test of November 3). Assuming a decay slope of 1.2, the date of fission products formation from U-235 for this sample would have been the first week of December, 1958.

In these estimations of decay rate and formation date, it was assumed that the air-borne particulates of a sample contain mixed fission products of a single test detonation. If a mixture of fission products from several detonations is present, the decay rate will change with time since the presence of fission products from earlier shots will decrease the decay slope. Although this has not been experienced with the more active samples, the decay rate of low activity samples does change and initial decay slopes of about 1.2 sometimes decrease to slopes more nearly 1.0 after a few months.

Beta Activity of Air-borne Particulates

The air-borne particulate beta activity varies in amount depending on many factors such as nearness to site of detonation, type of burst, weather conditions causing dispersal, etc. Generally speaking, during 1954, 1955, and most of 1958, the detonations occurred many thousand miles away (Pacific, Siberia, Arctic, or USSR) so that the air-borne particulate beta activity was relatively well distributed over the entire country as shown by the fact that fluctuations in activity occurred in waves of moderate amplitude and long length. Usually the half-life values indicated fission products of one to three months of age. Some were even older than three months, but by this time the concentration had fallen so that half-life measurements obtained were somewhat unreliable. In 1959, when there were no nuclear detonations, the air-borne beta activity was even more uniformly distributed over the United States. Under these conditions, weekly or bi-weekly tests on samples from near the mid-point of a state would probably


U.S.S.R.
U.S. PAC.
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S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N
50
40
30
20
10
0
PICOCURIES PER CUBIC METER
1953
1954
1955
1956
1957
1958
1959

FIGURE 5. Beta radioactivity of air particulates, national monthly average.

define the concentration of air-borne beta radioactivity.

On the other hand, following the continental (Nevada) tests of 1955, 1957, and 1958, low altitude atomic clouds were formed which spread horizontally along a broadening course in narrow bands, occasionally giving rise to "unusually" high concentrations of beta activity in the vicinity of the test site with relatively low values on either side of the cloud. Since the clouds generally moved from West to East, the observed air particulate activities also decreased from West to East due to diffusion and washout (rainout). The dispersal of specific atomic clouds has been carefully documented by List.[6]

The monthly national average beta activity and dates of nuclear explosions[7] are shown graphically in Figure 5. (Detailed tables of the data for the monthly air-borne particulate beta radioactivity values by groups of states and national total are available from the authors.) The periods of highest activity were the spring of 1955, the summer of 1957 and the fall, winter and spring of 1958–1959. These peaks are generally correlated with continental tests of nuclear devices. The beta activities during 1954 and 1956 were relatively low and, as can be seen, there was no continental testing. The average activities for March 1955, and for August 1957, were each heavily influenced by one sample of unusually high activity, namely, 2644 and 5435 picocuries per cubic meter, respectively. These samples of high activity were collected at sampling sites situated near the Nevada test site. In general, the higher activities from continental detonations represent rapidly decaying nuclear debris and, because of the high decay rate, they were not as significant as, for instance, the 3 to 6 month old fission product activity of 9 to 6 pc/m^3 occurring from January to May, 1959.

The year 1959 is of further interest in that there was no testing of nuclear devices. Yet, due to detonations toward the end of the previous year, the beta activity remained rather high throughout the first five months. The air-borne particulate activity declined rapidly and after July the average activity at most stations was less than 1 pc/m^3.

The frequency distribution of monthly average activities and annual averages are shown in Table I.

Radioactivity by Longitudinal Groupings

The year 1958 represented one of active nuclear testing by the United States, USSR, and the United Kingdom. It also represented the first full year when approximately 80 air-borne particulate samples were collected and tested weekly for radioactivity.

The radioactivity data on IBM cards have been subjected to a variety of correlations to find seasonal or regional trends in radioactivity

TABLE I
Frequency Distribution of Monthly Average Beta Activity

Year	Total Months	Number of Months in indicated range (pc/m³)				Annual Average pc/m³
		0–1.0	1.1–5.0	5.1–15	>15.1	
1953	4	4	—	—	—	0.3
1954	12	7	5	—	—	1.0
1955	12	5	5	1	1	4.6
1956	12	—	11	1	—	2.3
1957	12	—	7	3	2	8.2
1958	12	—	6	6	—	5.7
1959	12	5	2	5	—	4.0

concentration and age as related to nuclear tests. One of the more worthwhile correlations was obtained by a longitudinal grouping of the stations as shown in Figure 6. The results for three of the five groups of states are presented graphically in Figure 7. The activities for the Pacific Coastal states are generally the same or lower than those of the East Central or Atlantic Coastal states. The significant exceptions occurred in October following Nevada tests and, to a lesser degree, a few weeks in March, and again in November. During these periods it is pertinent to observe that the half-life values were sometimes lower than usual. Particularly striking are the higher average activities from the high altitude sampling stations of the mountain area.

The activities for the West Central and those for the Atlantic Coastal states are not shown graphically because the magnitude of difference would not appear significant on the scale used.

A comparison of fission product half-life and the date of occurrence of known nuclear tests indicates that air-borne activity for all months of 1958 was due to U. S. and U. K. Pacific, or USSR detonations, except that during the latter part of October and early November the effect of the Nevada tests was evident. It is also significant to observe that several weeks usually pass before nuclear bomb debris from the U. S. and U. K. Pacific, or USSR tests reach this continent.

Air-borne Particulate Radioactivity

The significance of inhaling air-borne radioactive particles originating from the detonation of nuclear devices necessarily requires the application of a radiation concentration guide for mixed fission products in air. This guide is dependent on the permissive radiation dose and a knowledge of the behavior of inhaled radioactive particles of various sizes and solubilities which, when deposited on lung surfaces, remain fixed, are cast off by coughing and expectoration or swallowed, or enter the blood stream and are excreted or deposited in specific organs.

Standards or guides of permissive exposure to the whole body or critical organs have been recommended or suggested by the National Committee on Radiation Protection and Meas-

FIGURE 6. Longitudinal grouping of stations.

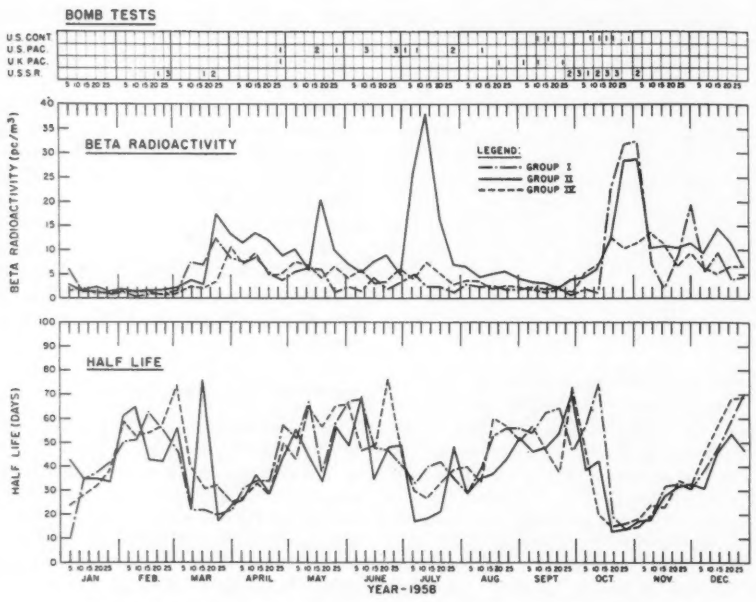

FIGURE 7. Radioactivity and half-life by groups of stations, 1958.

urements,[8] the International Commission on Radiological Protection,[9] the National Academy of Sciences-National Research Council[10] and the Federal Radiation Council.[11] All are in essential agreement with the principles of limiting man-made exposures and recommend or suggest comparable permissive exposures.

The Federal Radiation Council recommends dose guides wherein a radiation worker is permitted a whole body dose of 3 rem per 13 weeks or a total accumulated dose of 5 times his age in years less 18; a body burden to bone of 0.1 microgram of radium-226 or its biological equivalent, or a dose of 5 rem in any 13 weeks or 15 rem per year to organs (lung) other than active blood-forming organs, gonads or lens of eye. The recommended dose guide for an individual of the general population is 0.5 rem for whole body or about 0.1 the guide for radiation workers, and is identical to recommendations of the NCRP. The guide for an individual of the general population is reduced by a factor of three when applied to the average gonadal exposure in a reasonable population group. Since the air-borne mixed fission products from the detonation of nuclear devices have been the principal sources of air contamination, the greatest radiation hazard is to the lung, G.I. tract, and bone, but not to organs where genetic changes are most likely to occur. In fact, since the NCRP and FRC arbitrarily lowered the dose guide for a radiation worker by a factor of ten to apply to individuals of the general population, there is justification for considering a dose guide of 0.5 rem per 13 weeks or 1.5 rem per year for insoluble nuclides critical to lung tissue.

According to NCRP,[8] "because the direct determination of the body burden or the dose to an organ or to the total body is generally difficult, and because in most cases measures to decrease the body burden are rather ineffective and difficult to apply, the only practical procedure for general protection of occupational workers is to limit the concentration of the various radionuclides in the water, food, or air available for consumption ... (thus) ... the recommended values of maximum permissible total body burden and maximum permissible concentrations in air and in water ... are computed for occupational exposure (15 rems/yr. for most individual organs of the body except bone which is 0.1 μg Ra-226 or equivalent) ... for 50 years of continuous exposure."

The Federal Radiation Council[11] introduced the term Radioactivity Concentration Guide (RCG) to replace the term Maximum Permissible Concentration (MPC) but did not recommend the numerical values other than to

suggest the continued use of current concentration guides, namely 1/3 of 10 per cent of the occupational MCP for interim use.

Assuming that not more than 33.3 per cent of the radiation exposure is from the inhalation of bomb debris and the remainder, or 66.7 per cent, from other sources, such as food, water, and external radiation, then a Radiation Concentration Guide for radionuclides in air $(RCG)_a$ may be defined as one per cent of the MPC for a 168-hour week (see Table I of NCRP report)[8] for bomb debris (assumed to be mixed fission products, MFP, from the instantaneous slow neutron fission of U-235). Many radionuclides contribute to the MFP-$(RCG)_a$, depending on the relative abundance of individual nuclides of a given age and the $(RCG)_a$ value of each. The abundance of 32 of the most significant radionuclides present at fixed intervals after detonation were obtained from tables given by Bolles and Ballou[5] and have been used in conjunction with the $(RCG)_a$ of each nuclide to derive the $(RCG)_a$ for MFP. This weighted $(RCG)_a$ for MFP is the reciprocal sum of the fractional abundance of each radionuclide divided by its $(RCG)_a$ (see formula on Page 18 of Handbook 69).

The summation of the fractional abundances for a mixture of fission products (MFP) of given age (selected to show the effect of age on the (RCG)a usually totaled somewhat less than 1.0 because fractional percentages of many unimportant nuclides had been omitted.[12] Nevertheless, the (RCG)a was computed on the assumption that omitted nuclides were as hazardous as the mixture of the 32 more important nuclides.

The lung was the most critical organ for 24 of the 32 nuclides of greatest significance. Of these, ruthenium-106, cerium-144, and cesium-137 with $(RCG)_a$ of 20, 20 and 50 pc/m^3 appear most significant. The eight nuclides, where the lung was not the most critical organ, are strontium-89 and 90 (bone seekers), the iodines (thyroid seekers) and molybdenum-99, rhodium-103, rhodium-106, and cerium-143 (critical to G.I. tract).

The $(RCG)_a$ of 32 individual nuclides for critical organs[8] and the abundance of them at 10 different ages[5] were used to determine the weighted $(RCG)_a$ for MFP. The results presented in Figure 8 show that the $(RCG)_a$ in picocuries (10^{-12} curies) per cubic meter of air varies from about 200 for 3.12-day old mixed fission products to about 100 for 3-month-old mixed fission products. Thereafter, the $(RCG)_a$ drops to about 30 pc/m^3 for one-year-old MFP, 15 for 2-year-old, six for 5-year-old, and less than one for 8-year-old mixed fission products. Since the

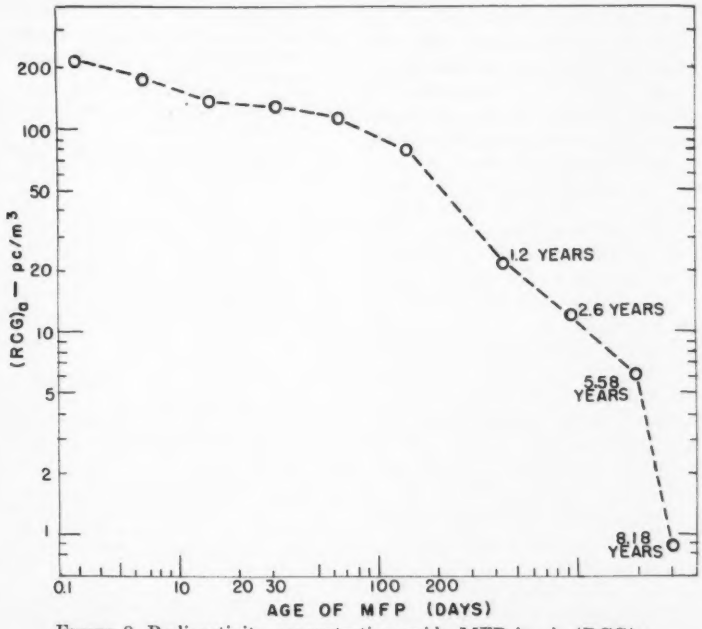

FIGURE 8. Radioactivity concentration guide MFP in air (RCG)a.

$(RCG)_a$ varies with age, the mean age of air-borne radioactivity must be determined by radionuclide analysis. In the absence of radionuclide analysis (in air or rainout) the radioactive decay rates are valuable indicators of age from which $(RCG)_a$ for MFP may be evaluated.

During the last five years the highest annual average air-borne particulate radioactivity has been the equivalent of about 5 pc/m³ of 1- to 3-month old fission products as compared to an (RCG)a of 100 to 150. Thus, for the present, this source of man-made radiation exposure appears quite insignificant.

Summary

The air-borne particulate radioactivity data of the National Air Sampling Network have been summarized for the period October, 1953, through December, 1959.

The significance of observations must be interpreted in terms of the activity concentration and the age of the fission products as compared to the Radioactivity Concentration Guide or a fraction of it.

A detailed analysis of 1958 results, when each of three nations conducted many nuclear tests, showed that the half-life of bomb debris arriving from across the Pacific Ocean was usually more than three weeks and usually less than three months as observed in the United States.

Air-borne particulate radioactivity observed in the United States represents a fractional part (less than 5 per cent) of the Radioactivity Concentration Guide for Air $(RCG)_a$.

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Distribution and Excretion Studies in Dogs Exposed to an Aerosol Containing Polonium-210

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Following brief, single exposures of dogs to an aerosol containing polonium it was found that 64% of the inhaled polonium was deposited within the animal. Thirty days after exposure the lungs contained 32–49% of the total body burden. In the interval 28–149 days post-exposure the biologic half-time for clearance of the lung was 36 days; that for whole body clearance was 37 days. Removal of the deposited dust appeared to be governed chiefly by the rate of removal of the polonium from the lungs. Fifty per cent of the deposited polonium was excreted in the first three days, the principal route being via the feces. Distribution patterns and estimates of radiation dose are presented.

Introduction

THE fate of material inhaled and deposited in the respiratory tract is of considerable interest. Such information may be of use in determining the manner and degree to which the respiratory tract is cleared of dust. Information may be forthcoming as to the amounts of material likely to be retained in the lung and which might thereby lead to dysfunction of the lung tissue. If the inhaled material were radioactive, information as to its fate would be of use in predicting the hazard to the lung and other organs from the attendant radiation.

A study previously reported by Morrow and Gibb[1] has described the deposition of Po^{210}, carried on a submicronic sodium chloride aerosol, in the respiratory tract of dogs. It is the purpose of this report to describe the subsequent fate of this deposited polonium.

Materials and Methods

As described previously,[1] six dogs were exposed for intervals of 20–40 minutes to an atmosphere containing polonium-210 chloride carried on a sodium chloride vector aerosol of CMD 0.04 μ, $\sigma g 2.3$; the mass concentration of sodium chloride was 10–30 mg/m^3. Exposure conditions and equipment have been described by Morrow, *et al.*[1, 2, 3, 4] The aerosol generator was of the type described by Lauterbach, *et al.*[5]

Following inhalation of the aerosol, the dogs were returned to individual metabolism cages where they were maintained for periods up to five months before being sacrificed. Urine and feces were collected daily during the first post-exposure week, less frequently thereafter, and analyzed for Po^{210} content. Upon sacrifice the animals were exsanguinated by perfusion with heparinized saline in order to reduce the blood content of the organs as much as possible; this was 80–90 per cent complete. Various organs were removed, and these and the remaining carcass set aside for determination of Po^{210} as described by Smith, *et al.*[6]

Daily excreta were not collected after the first post-exposure week; however, sufficient samples were taken to permit construction of plots from which excreted Po^{210} could be estimated for those days samples were not taken. These estimates for each dog are included with the quantities measured in the excreta, perfusate, organs and carcass as a measure of the total Po^{210} recovered. The data to follow are presented in terms of this total as a measure of the total Po^{210} deposited in each dog. The results

Portions of this work were presented at the 19th Annual Meeting of the American Industrial Hygiene Association, Atlantic City, New Jersey, April 22-25, 1958.

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An earlier version of this report is to be found in University of Rochester Atomic Energy Project Report UR-566 (cf. ref. no. 9).

of all analyses have been corrected for radioactive decay for the interval between inhalation and analysis, *i.e.* for the purposes of this presentation Po^{210} is considered to be a stable, non-radioactive dust.

Results

Deposition and Absorption

The percentage deposition of inhaled Po^{210} in the six dogs, together with the total microcuries deposited, is shown in Table I. The percentage of inhaled dust deposited in the respiratory tract was 48.2–77.3%, with an average deposition of 63.6%. The deposition has been described in detail by Morrow and Gibb.[1]

TABLE I
Deposition and Absorption of Inhaled Po^{210} in the Dog

Dog No.	Per Cent Inhaled Po Deposited[1]	Total μc Deposited (Dose)[2]	Per Cent of Dose "Absorbed"	Days Post-Exposure to Sacrifice
4111	70.6	20.0	29.7	28
4200	48.2	40.5	32.3	29
4188	77.3	10.2	20.3	116
4160	55.3	23.4	13.7	131
4072	65.7	26.2	8.5	146
4112	64.3	31.2	6.8	149

[1] Calculated from analyses of inspired and expired air and total volume of air breathed.

[2] Calculated from total Po^{210} recovered from all tissues, perfusates and excreta.

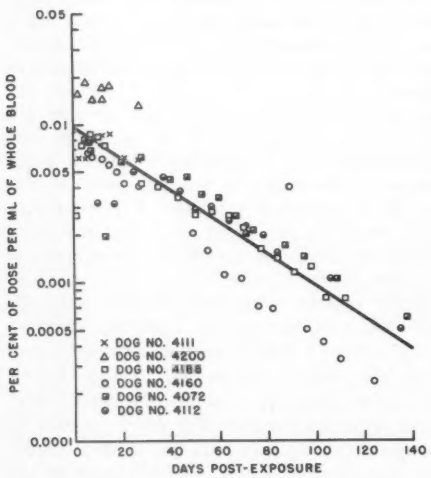

FIGURE 1. Polonium in blood as per cent of dose per ml of whole blood.

The quantity of deposited Po^{210} which is absorbed can be estimated by correcting the total Po recovered in the blood, urine, tissues and carcass for that Po remaining unabsorbed in the lungs. These data, expressed as the per cent of dose which is absorbed are also shown in Table I. The decrease in absorption with increasing time suggests that a portion of the absorbed Po^{210} which should have been accounted for in the blood-urine-tissue-carcass pool has been shifted into the fecal fraction. Presumably, this has been accomplished by biliary excretion of absorbed Po^{210} into the gastrointestinal tract. This is supported by the fact that at all times the quantity of Po^{210} in the feces exceeded that in the urine. Direct observation of biliary excretion of Po^{210} has been reported by Morrow, *et al.*,[7] and by Fink.[8]

Transport

Following deposition of the inhaled aerosol a portion of the material enters the bloodstream perhaps by direct absorption from the lung, by lymphatic drainage, and certainly by intestinal absorption of material moved up the respiratory tract and swallowed. The per cent of dose per ml of whole blood at different time intervals following inhalation is shown in Figure 1; it is seen to decrease in regular fashion with increasing post-exposure time. The percent of dose per ml of whole blood may be estimated from the equation:

$$\text{Per cent of dose per ml blood} = 97.43\ e^{-0.0231y} \times 10^{-4}$$

where y is days post-exposure.

In many instances samples of plasma and of red blood cells were also analyzed. Maximal concentrations in both tissues were achieved 5–15 days after exposure. Throughout the post-exposure interval the per cent of dose in the cells exceeded that in the plasma.

Tissue Distribution[9]

The body burdens of Po^{210} found in these dogs at sacrifice are listed in Table II, and shown graphically in Figure 2. The body burden is seen to decrease in a regular fashion with increasing post-exposure time after 28 days. The rate of removal is characterized by a half time of 37 days. The body burden at y days post-exposure, expressed as per cent of the dose is closely approximated by the equation:

$$\text{Body burden as per cent of dose} = 65.6\ e^{-0.0187y}$$

where y is 28 or more days post-exposure.

The tissue distribution of this body burden among the five lung lobes and several other organs is shown in Table III. As would be expected, the fractions 28–29 days after exposure were greatest in the whole lung; 32–49% of the body burden at this time was located in this organ. However the proportion localized in the pelt was at least as great as that in the various lung lobes. Early concentrations in the liver and kidneys also approximated those in the lung lobes. Concentrations in the lungs decreased with time, but that in the pelt increased. No Po^{210} was deposited either upon or within the pelt at exposure, inasmuch as only the animals' noses were exposed. At 146 days and later, half or more of the body burden was localized in the pelt, suggesting the importance of this tissue as a site of Po storage. A comparable uptake of Po^{210} by the pelt was seen in gastric absorption studies in the cat.[7]

Quantitatively, of the 34 tissues analyzed only the liver, kidneys, pelt and circulating blood volume contained more than one per cent of the body burden throughout the 28–149 day post-exposure period. Each lobe of the lung generally contained more than one per cent of the burden throughout the first 116 days, and the upper left and lower right lobes generally contained more than this throughout the entire period studied.

Few data are available at comparable exposure times to permit comparison of the per cent of body burden per organ in different species receiving Po^{210} by inhalation. However, the distribution seen here in the dog after 28–29 days is very similar to that seen by Casarett[10] in the rat 30 days after inhalation. The results of Berk and DiPasqua[11] are similar.

Plots of the change in organ burden with time in the whole lung and in the pelt are shown in Figure 3. The rate of removal of the dust from the lung is characterized by a half-time of 36 days; the per cent of body burden remaining in the lung at y days post-exposure is approximated by the equation:

$$\text{Lung burden as per cent of body burden} = 67.0\, e^{-0.0192y}$$

where y is 28 days or more post-exposure.

It is immediately apparent that the rates of removal of the whole body burden and of the lung burden are very similar. In other words, the rate of over-all removal from the body is governed by the rate at which the dust load is cleared from the lungs.

The half-time for removal of the dose in the interval 0–28 days cannot be determined from Figure 2, because no sacrifices were made during the first month. However, the Po^{210} excreted in both feces and urine was measured daily during the first week post-exposure; total cumulative excretion is thus known during this interval. Hence, whole body burden as per cent of the dose can be estimated from the expression (100 − total cumulative excretion as per cent of dose).

TABLE II
Body Burden of Po^{210} in Dogs Following Inhalation

Dog No.	Days Post-Exposure	Body Burden as Per Cent of Dose
4111	28	39.3
4200	29	37.0
4188	116	9.5
4160	131	3.9
4072	146	5.0
4112	149	4.9

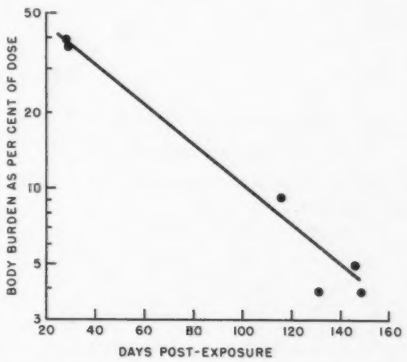

FIGURE 2. Body burden of polonium at sacrifice as per cent of dose.

TABLE III
Tissue Distribution of Absorbed Po^{210} as Per Cent of Body Burden[1]

Organ	Per Cent of Body Burden at					
	28 days	29 days	116 days	131 days	146 days	149 days
upper left lung lobe	8.49	3.33	1.08	0.62	1.29	1.05
lower left lung lobe	13.21	9.98	1.05	1.67	0.87	0.44
upper right lung lobe	10.00	5.70	1.39	0.66	0.54	0.99
middle right lung lobe	3.34	4.46	0.73	0.58	0.73	0.60
lower right lung lobe	13.72	8.05	2.26	1.79	1.20	0.58
whole lung	48.76	31.52	6.51	5.32	4.63	3.66
liver	6.48	6.02	14.10	6.53	9.24	2.73
kidneys (both)	18.29	19.97	11.00	14.49	16.43	28.95
blood volume	2.36	7.71	5.93	1.88	7.44	5.43
pelt	11.42	15.05	44.34	42.77	53.72	50.85

[1] See reference 9 for distribution among 25 other tissues.

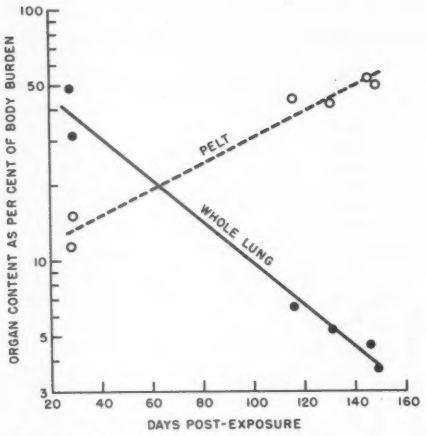

FIGURE 3. Organ content of polonium as per cent of body burden.

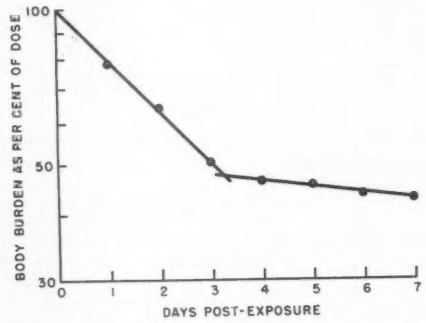

FIGURE 4. Body burden of polonium as per cent of dose during first week of exposure.

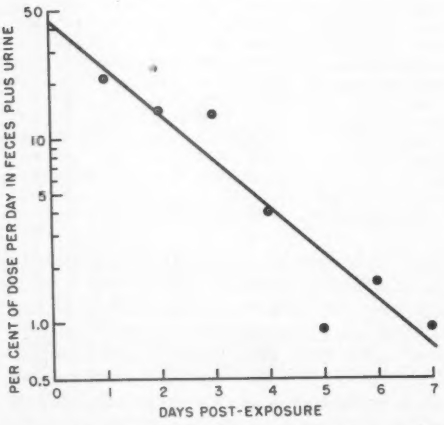

FIGURE 5. Excretion of polonium during first week as per cent of dose per day in feces plus urine.

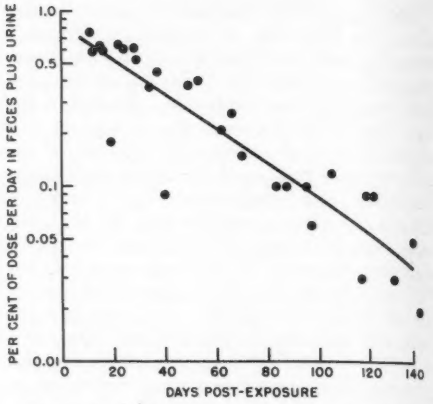

FIGURE 6. Excretion of polonium 11–143 days post-exposure as per cent of dose per day in feces plus urine.

Body burden as per cent of dose in the initial post-exposure week is shown in Figure 4.

It is apparent that removal of the body burden proceeds in at least two phases. Half-time for the more rapid phase is three days, while for the slower phase it is 37 days. It is further evident that 50% of the inhaled dust which is deposited is removed in approximately three days. From this it may be inferred that about half of the inhaled Po^{210} is deposited in the upper respiratory tract and ciliated epithelium, and half is deposited in the lower portion of the tract.

Excretion

Mobilization and excretion of the deposited Po^{210} was high during the first week after exposure; 57% of the dose was excreted in this interval. Excretion continued to decrease thereafter, and was less than 0.1% per day in the later post-exposure period.

The average daily excretion of Po^{210} in the feces plus urine, as per cent of dose, for the first seven days and for the interval 11–143 days post-exposure are shown in Figures 5 and 6, respectively. Equations for the per cent of dose excreted daily are:

$$\text{Daily per cent of dose in feces + urine} = 43.8\, e^{-0.602y}$$

where y is one to seven days post-exposure, and

$$\text{Daily per cent of dose in feces + urine} = 0.82\, e^{-0.0223y}$$

where y is eleven or more days post-exposure.

Fecal excretion invariably exceeded that in the urine. Large amounts were excreted in the feces in the first few days after exposure, due chiefly to rapid movement of deposited Po^{210} up the respiratory tree to the trachea, and thence to the gastrointestinal tract.

The total Po^{210} excreted by each dog during the course of the experiment is recorded in Table IV. More than 60% of the dose was excreted in the first 28–29 days following exposure; total excretion equaled or exceeded 95% at 131 days and later. Fecal excretion accounted for more than 84% of the total excreted in the first month post-exposure, and for 90% or more of that excreted after 131 days.

Radiation Dose[9]

Radiation received by the five lung lobes was reasonably constant in any given animal, the variation from lobe to lobe being 1.5- to 3.5-fold among the six dogs. The dose to the whole lung ranged from 82 to 304 rads. Direct comparison among the dogs cannot be made, of course, inasmuch as the total microcuries administered varied from dog to dog.

These estimated radiation doses resulted in minimal or questionable tissue changes. The only lesions seen which might be attributed to radiation were in the lungs of dog nos. 4072 and 4200. The pulmonary lesions seen in these two dogs were difficult to evaluate; they may represent a response to radiation, or a reaction to some other type of injury. In some respects they were similar to radiation fibrosis observed in humans and in other respects they were dissimilar. Further work at low levels of radiation and for longer observation periods is indicated.

Autoradiography[9]

At the earliest time periods available for study (28 and 29 days), virtually all of the autoradiographically demonstrable polonium was observed as single alpha tracks, indistinguishable from an ionic or soluble form.

The single track population was distributed uniformly in all organs, except for lesser concentrations in and on the tissues of the bronchial tree, and except for greater concentrations in the epithelium of the proximal convoluted tubules in the kidney. Autoradiograms of skin sections showed that the fraction of the body burden found in this tissue apparently is due to activity in the hair follicles, where the concentration is higher than in the surrounding structures. Po^{210} also appeared to be concentrated to some extent in the hair itself, being demonstrable in hair clippings.

TABLE IV
Cumulative Excretion of Po^{210} as Per Cent of the Dose

Dog No.	Days Post-Exposure	Per Cent of Dose in		
		feces	urine	total
4111	28	51.0	9.5	60.5
4200	29	55.9	7.0	62.9
4188	105	79.1	11.4	90.5
4160	131	86.2	10.1	96.3
4072	143	91.3	3.7	95.0
4112	140	93.0	3.0	96.0

Discussion

The average percentage deposition of inhaled Po^{210} in these six dogs was found to be 63.6%. This is in excellent agreement with the average value of 63.4% found by Morrow, *et al.*,[3] for 17 experiments on seven normal human subjects breathing a sodium chloride aerosol. On the other hand, Casarett[10] determined the average percentage deposition of inhaled Po^{210} to be 33% in the rat, and Berke and DiPasqua[11] reported an average figure of 53% in this species. In each of these studies also the polonium was carried on chloride; CMD's were 0.052, 0.046 and 0.098 μ in those reports,[3, 10, 11] respectively. Apparently the rat behaves differently with regard to the deposition of these aerosols than does man or the dog.

Analyses of excretion data shows that clearance of the deposited Po^{210} appears to proceed in at least two phases, the resultant of which leads to the removal of half of the initial dose in three days. There is an initial rapid removal of material from the respiratory tree to the gastrointestinal tract which is characterized by a half-time of three days. In all likelihood, the greater portion of this material comes from that deposited on the ciliated epithelium of the respiratory tract. In the second phase, probably representing chiefly removal of material from the lower respiratory tract, the dust is removed at a rate characterized by a half-time of approximately 37 days. Casarett[10] has reported that in the rat removal of Po deposited following inhalation proceeds also in a two phase system, characterized by half-times of 1.5 and 30 days. In both species, then, the kinetics of removal appear to be similar in the second phase, at least as regards the half-time constant.

From Figures 2 and 3 it is seen that the lung and body burdens present at 28 days are cleared with a half-time of 36–37 days. Removal of deposited Po^{210} from these dogs is governed chiefly by the rate at which the material is removed from the lungs. Clearance of the dust

from the individual lobes proceeds at somewhat different rates. Plots (not shown) of the lung lobe data of Table III indicate the half-times for clearance of the five lobes to range from 43 to 28 days. The lower left and upper right lobes are cleared the most rapidly. It should be emphasized that these half-times apply to the interval 28–149 days post-exposure. Casarett found a half-time of 17.5 days in the rat for the 30-day period following exposure. Berke and DiPasqua on the other hand, determined the half-time to be 9.5 days for the first 30 days following exposure, and 42 days for the second 30-day interval.

It is interesting to note that Rahn, *et al.*,[12] have shown that the different lobes of the dog lung are ventilated to different degrees, and that Stokinger, *et al.*,[13] have found the five lobes of rat lungs to be cleared of deposited dusts at different rates.

Few reports are available describing the course of urinary excretion of Po in man following inhalation exposures. From data of Naimark[14, 15] describing presumed inhalation exposures it may be calculated that the effective half time of Po^{210} in 21 human subjects ranged from 21.7 to 45.5 days, with a mean half-time of 33 days. The first indication of exposure in these subjects was found during the assay of routine weekly urine samples. Hence, exposure might have occurred 1–7 days previously. No indication was given by Naimark of a multiphase removal pattern, but if an earlier, more rapid, phase occurred, it might have been missed in the first post-exposure week. It seems reasonable to conclude that the half times found by Naimark refer to the later post-exposure intervals. Urinary excretion in the two cases reported by Foreman, *et al.*, (16) showed two components; half-time of the initial component in both instances was 0.75 days, while that of the second component was 37 days in one instance, 47 days in the other. In our experiments with dogs, the effective half-times of the earlier and later phases were found to be approximately 3 and 30 days, respectively.

The excretory pattern of Po^{210} absorbed by the dog after inhalation exposure indicates the principal route of excretion to be via the gastrointestinal tract and feces. In the first three days immediately following exposure the per cent of the dose appearing in the feces was more than 12% per day, while only 1.9% or less per day appeared in the urine. The fraction in each decreased with increasing post-exposure time, but in 55 of 58 instances where both excreta were analyzed, the fraction in the feces exceeded that in the urine. This situation prevailed even at 149 days post-exposure, at which time it would not be expected that phagocytic removal of Po to the gastrointestinal tract would contribute significantly to the fecal load. The importance of movement of dust up the respiratory tree and into the gastrointestinal tract, and perhaps of movement into the intestine via the biliary system is clearly evident.

It is of interest to compare the deposition and clearance rates assumed in the recommendations of the International Commission on Radiological Protection (ICRP)[17] with those actually found in this study. The model assumes a deposition of 75% of any inhaled dust; under the conditions of this experiment polonium deposition ranged from 48 to 77%. These ICRP recommendations[17] do not indicate an assumed half-time for clearance of the upper respiratory tract; in our experiment the nasopharynx and bronchial tree was cleared at a rate characterized by a half-time of three days. According to the ICRP,[17] the body burden in these dogs should have been 6.25% of the dose at 120 days, and in actuality, was found to be 7.3% at 120 days. Our experimental findings agree fairly well with the model situation as represented in the recommendations of the ICRP. Insofar as the particular experiments described in this report are concerned, it is seen that the ICRP assumptions are, indeed, on the safe side; that is, amounts of dust deposited and retained are overestimated.

It is obviously of importance to have available some ready means of estimating the lung and body burdens of persons who are inadvertently exposed to atmospheres containing toxic dusts. For reasons of simplicity it would be highly desirable if such an estimation could be based upon the analyses of blood and/or excreta samples obtained at a known interval following the exposure. Appropriate manipulations of the equations given previously give rise to the following expressions:

$$\text{Dose} = 10264\, e^{0.0231y} \times \mu\text{c/ml blood} \qquad (1)$$

where y = days post-exposure.

$$\text{Dose} = 2.283\, e^{0.602y} \times \mu\text{c in 24-hr. collection of feces + urine} \qquad (2)$$

where y = 1–7 days post-exposure.

$$\text{Dose} = 121.95\, e^{0.0223y} \times \mu\text{c in 24-hr. collection of feces + urine} \qquad (3)$$

where y = 11–149 days post-exposure.

$$\text{Body burden} = 6733\, e^{0.0044y} \times \mu\text{c/ml blood} \qquad (4)$$

where y = days post-exposure.

Body burden = $1.4976\ e^{0.5833y} \times \mu c$ in 24-hr. collection of feces + urine (5)

where y = 1–7 days post-exposure.

Body burden = $80.000\ e^{0.0036y} \times \mu c$ in 24-hr. collection of urine + feces (6)

where y = 11–149 days post-exposure.

Lung burden = $4511\ e^{-00.0148y} \times \mu c$/ml blood (7)

where y = days post-exposure.

Lung burden = $1.0033\ e^{0.5641y} \times \mu c$ in 24-hr. collection of feces + urine (8)

where y = 1–7 days post-exposure.

Lung burden = $53.600\ e^{-0.0156y} \times \mu c$ in 24-hr. collection of feces + urine (9)

where y = 11–149 days post-exposure.

By means of the above expressions, then, it is possible to calculate the initial dose and the lung and body burdens from the analysis of a blood sample or of a pooled urine and feces sample, provided that the elapsed time between exposure and sampling is known.

However, it should be realized that the equations developed here, which apply to the circumstances of the experiments described, might not apply with equal validity in other species, or with other aerosols of different physical and chemical properties and therefore may not be applicable to human exposure.

Summary

Deposition of inhaled polonium chloride in the dog resulted in a mean deposition of 64% of the Po^{210}. Following deposition, peak blood concentrations were reached 5–15 days after exposure. The whole lung contained 32–49% of the total body burden approximately 30 days after exposure. Each lobe of the lung generally contained more than one per cent of the burden throughout the first 116 days, and the upper left and lower right lobes generally contained more than this throughout the entire period studied. The liver, kidneys, pelt and circulating blood volume were the only other organs containing more than one per cent of the body burden during the 149-day period. After 149 days the pelt contained 50% or more of the dose, principally in the hair follicles. This was not due to dust deposition at the time of exposure. Fifty per cent of the deposited Po^{210} was excreted in three days; the principal route of excretion was via the feces. In the interval 28–149 days post-exposure the half-time for clearance of the whole lung was 36 days; that for the whole body was 37 days. Removal of the deposited dust appeared to be governed chiefly by the rate of removal of the Po^{210} from the lungs. It was suggested that analyses of samples of blood and excreta taken at known intervals after a single, acute exposure to Po^{210} by inhalation may be useful guides to estimations of the initial dose.

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AWARD FOR BEST ARTICLE

THE MICHIGAN INDUSTRIAL HYGIENE SOCIETY AWARD for the best article appearing in the American Industrial Hygiene Association Journal during 1960 was presented to Dr. Bernard E. Saltzman, Mr. Howard L. Kusnetz, and Mr. Marshall E. LaNier for their article "Calibration and Evaluation of Gas Detecting Tubes." In the above photo Dr. Saltzman is shown accepting the award for the authors from Mr. Donald L. Eschelbach, President of the Michigan Industrial Hygiene Society.

The Elements of an Effective Comprehensive Radiation Control Program

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Presenting an evaluation of the realistic and practical aspects of protecting the general public from hazards of ionizing radiation, the author advocates concentrating inspection and control efforts on the hazards with respect to their significance in relation to dose and probability of exposure.

Introduction

THE protection of the human race against immediate and long range harmful effects of radiation exposure is a field which has grown up very rapidly in the past few decades. It includes a number of closely related but widely different professional specialties. Studies range from those concerned with the possible effects of infinitesimal increase in exposure of the whole population which could result in changes appearing a dozen generations from now, to the prevention of accidents that could kill instantaneously.

There is perhaps more money being spent and more manpower being employed in the study of radiation effects than in the case of any other occupational or public health danger. Because of the rapid growth of this field and also because many of the effects of radiation are still unknown, the relative importance or unimportance of any particular aspect is widely misunderstood by most of the general public. On the other hand, because of highly publicized reports of the few serious radiation exposures and nuclear accidents, particularly when related to man's instinctive desire to perpetuate the race, many people become emotionally concerned about some of those aspects which they do not fully understand. It must be acknowledged that today we have passed the point in the development of our field where we are concerned primarily with the protection of individuals against any demonstrable injury. We are mostly concerned now with the possible degradation of our race.

Today we observe incongruities in the practice of our field of health physics (or radiation hygiene, radiation control or whatever you prefer to call it). Newspaper reports and television broadcasts devote considerable time to the possible effects of exposing people to something of the order of one or two mrems per year because of residual fallout effects at the same time that some physicians are exposing the major part of patients' bodies unnecessarily to about 10 mrem in a fraction of a second because of an unawareness of some of the simple rules which should be employed in the application of x-rays. We are indeed fortunate today that through untiring efforts of much-abused committee members we have a widely accepted set of exposure standards for radiation workers and for the general population. Nevertheless, there are inconsistencies in the application of the rules such that it would appear that now is the time for a consideration of certain standards of application.

Program Planning

It might be well for us to examine carefully radiation control problems and methods of dealing with them in terms of their actual importance in reducing exposures. Controls, problems and methods which should be so considered include; use of radiation shields, waste disposal, use of warning signs and labels, mechanical restrictions of interlocks, radioactive contamination and radiation surveys. Many of the radiation control standards today are mechanical in nature, similar to some of the mechanical aspects of electrical dangers or fire or explosion hazards. In reviewing some programs there seems to be a lack of distinction between the purely control or regulatory aspects and the public relations or educational aspects. Experience has shown that an electrical inspector to be most effective and efficient devotes his entire time to inspecting for certain clearly expressed electric standards rather than sitting down with

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the user of electrical equipment to educate him as to its safe use. It might be well for us to follow the examples of these other similar fields in which there have been many years of experience. It may be that we should look more carefully at the educational standards required for many of the inspection functions. We find that some regulatory agencies would like to engage Ph.D. physicists to administer and carry out its radiation control programs. The average Ph.D. physicist would by no means be satisfied nor, in fact, particularly well suited to spending his time and attention in the vast majority of inspection functions which are necessary.

Before planning the task of setting up a radiation inspection program for the city of New York, which already has over 13,000 registered radiation installations to be inspected, we reviewed programs of other agencies both federal and local. Since our Code requires observance of the recommendations of the National Committee on Radiation Protection, we reviewed all of the hundreds of recommendations which might be applicable, and listed those which had been written in the "shall" or mandatory category, in order to determine which are most important. In each case, we listed the possible effect of not observing the particular recommendation in terms of any overexposure that was likely to occur, both as to its degree and likelihood of occurrence, as well as the number of persons that might be so affected. We also reviewed the inspection procedures and findings of those already doing radiation inspections.

As an example of our method of evaluating the relative importance of potential radiation hazards, let us compare two common ones. Consider the integral exposure of a typical 150-pound patient having a flat x-ray plate taken at about 90 kv and 50 ma-sec with a 10-inch by 12-inch film, and compare two risks; first, the exposure risk of not properly collimating the useful beam and, second, the risk of having the x-ray tube inadequately shielded. If the beam were properly collimated and filtered, the integral dose to a 10-inch thick section of the torso would be between 40 and 80 kilogram-roentgens. If the x-ray tube were shielded in accordance with NCRP specifications, the rest of the patient's body would receive an integral dose of about 0.01 kilogram-roentgens. This means that if the leakage radiation to the patient were doubled by inadequate tube shielding, it would be equivalent, in terms of total integral dose increase, to increasing the size of the useful beam striking the patient by less than a tenth of a percent. The increased gonad dose, because of inadequate tube shielding, would be unimportant since most such dose is from scatter. The increased gonad dose, by including them in the useful beam as a result of inadequate collimation, could be by a factor of hundreds.

The above example indicates that the collimation of the beam is extremely more important than the shielding of the tube and should therefore have a much higher priority in inspecting for deficiencies.

Similarly, any deficiency which exposes an x-ray technician or dental hygienist hundreds of times a week is much more important than one which might expose a visitor or patient once or twice occasionally. Proper arrangement of the x-ray controls and protective shields are in this category.

The concern for surface contamination is one which has frequently been exaggerated. Except in the case of a few rarely used highly toxic radioactive materials, there is no evidence that a moderate amount of surface contamination constitutes a health hazard. Its measurement is useful to detect careless work habits or locate unsuspected leaks causing air-borne contamination but in itself should not be cause for alarm. Many of the rules against eating and smoking in rooms where radioactive materials are used are not based upon any evidence of overexposure.

Medical and Dental X-rays

Experience and review of the literature indicate that by far the greatest source of radiation of the general public has been medical and dental x-ray equipment. Handbooks 59 and 69 on Permissible Dose and Concentrations, Handbook 76 on X-Ray Protection and Handbook 73 on Sealed Gamma Sources of the National Committee On Radiation Protection in effect constitute the basis of our radiation code. In reviewing other programs concerned with the control of medical and dental x-rays we found that considerable time was being devoted to such matters as the investigation of leakage from shielded x-ray tube housings and the investigation of scatter patterns from phantoms which are placed in position to substitute for patients. In our evaluation of the degree of hazard concerned, as well as the likelihood of occurring, these two points were found to lie far down on our scale of importance. For example, discussions with x-ray manufacturers indicated that there was an extremely small likelihood that in any particular model the shielding would be defective. As a result of many years of personal experience with x-ray equipment and discussions with others who have been concerned with the testing of x-ray equipment, we could learn

of no cases in which x-ray shielding has been omitted from a tube head or was found to be grossly inadequate; except in one or two cases where the equipment was the first unit of a new model being marketed. In most pieces of equipment the absence of a shield could be readily detected by a trained inspector because of a lack of proper counterbalance. In most cases, if the head itself were to be shaken, the tube inside would rattle because of the absence of the shield which also serves as a tube support. In some cases it had been reported that the shielding of the head was inadequate to the extent that the radiation being emitted was as much as 50 per cent over the permitted value in cretain directions. Experience has shown that if this occurs in a single piece of equipment, it will occur in all other units of the same model. A single test of each single model should suffice and save many man hours of valuable time in the field. Such information could be pooled by all regulatory agencies concerned.

Regarding the subject of scatter patterns, it appears obvious that for a particular energy and tube current with a particular field size and filtration which can easily be checked, the scatter pattern from a particular patient or phantom will be the same. The great variation in scatter because of the different size, shape and position of different patients is probably much more important in influencing the scatter pattern. It was found that much time was being used to investigate the dose rate from fluoroscopes. While this factor is quite important, it has been found that if the operating kilovoltage and current of a particular unit is known within reasonable limits and if the distance from the tube to the panel and the filtration are known, the output can be predicted closely enough for protective considerations. In those few cases where all of these factors cannot be learned, such as in the case of a completely enclosed fluoroscope where the tube location and filtration cannot be seen, a simple test with either a pocket type instrument or a photographic film or film badge could give, in an instant, all the necessary data needed by the inspector.

Extensive radiation surveys of medical diagnostic x-ray equipment conducted not only by our group but by others who have reported in the literature, indicate that the wide variation in the manner of use makes it virtually impossible for a surveyor in a short period of time to determine the amount of radiation that will travel in any particular direction during diagnostic radiology, except for two possible directions; down through the table, or in a horizontal direction toward a wall-mounted film holder. This means that except for those two positions which might be critical, any measurements made inside or outside of a shielded room in other directions are not very meaningful. In fact, the absence of shielding in a wall of an x-ray room, except for one that is subject to very great work loads, is a matter of relative unimportance. There are many diagnostic x-ray installations that have been tested with integrating detectors (such as a photographic film) which indicate that shielding is often not required except possibly when immediately adjacent to a continually occupied room housing individuals in the nonradiation worker category. In these instances, the use of test films for a period of a few weeks to a month will give a better indication of all of the factors involved, such as use factor, work factor and degree of shielding afforded by the building material.

A test of the lead glass used in control booths and in fluoroscopes can involve considerable skill and the time of a trained specialist. For practical purposes, however, a flash exposure utilizing a sensitive fluorescent screen will give the necessary information in most cases. There have been a few instances reported where the lead glass has become broken and common plate glass has been substituted. Such a test will easily distinguish between the two, and this is the only occasion where the radiation exposure is likely to be serious.

As far as the protection of an x-ray technician is concerned, Handbook 60 provides two rules that are virtually foolproof. If they are observed, there should be no need for conducting tests in a control booth if it is known that the booth is actually lead-lined. (The presence of lead shielding in a control booth can be determined more readily with a small radioactive source than by operating the x-ray equipment.) Existence of lead lining can usually be observed by looking at the upper edge of a control booth wall and it can always be confirmed by the use of a film badge by the technician for a short period of time. The two rules in Handbook 76 are that the exposure switch should be so located that the operator cannot make an exposure from an unshielded position and the other is that the control should be located either in a separate room or in a booth built within the same room. Any installation which does not meet these two mandatory NCRP rules of fifteen years standing should not be tolerated.

Some inspection programs have been concerned with the testing of lead rubber aprons and gloves required in fluoroscopy. The protective value of such materials is very closely related to the weight per square foot. With a little

experience an inspector can judge by lifting an apron or a glove whether or not it meets the usual protective standards as far as lead equivalence. A simple refinement would involve the use of a small hand spring scale together with an estimate of the area of protective material in the garment. Flexing the material with the hands will tell whether the lead rubber or other material has deteriorated through hardening, which sometimes occurs with age. The exact lead equivalent as specified by the standards is relatively unimportant. In case of question, a radiographic exposure against a standard lead echelon will give evidence as to its exact lead equivalence. The kilovoltage at which such a radiographic test is made is unimportant, since the material used in such garments is always a lead compound or an equivalent dense material in which the attenuation is relatively independent of radiation energy.

Almost all investigators of the radiation exposure of patients and operators report that one of the greatest sources of such exposure is in fluoroscopy. For any particular examination the total dose to any patient, and incidentally the scattered radiation to the operator, is directly and importantly related to the degree of eye adaptation of the examiner. For this reason facilities for eye adaptation and their proper use are most important. A careful examination should be made to see that any room used for fluorscopy has adequate facilities for complete darkening without light leaks at the edges of window shades or at the cracks of doors. Anyone who has worked in a photographic dark room knows that even a slight leak will spoil the adaptation of the eyes. It is known that at least ten or fifteen minutes of eye adaptation is necessary prior to fluoroscopy. It is also virtually impossible for the average busy physician to spend ten or fifteen minutes sitting in a completely dark room waiting for his eyes to become adapted. A valuable adjunct has been found to be the use of eye adaptation goggles. Any fluoroscopic operator therefore should use such goggles and their availability is considered by our agency to be a "must." Many of the older fluoroscopes use the foot switch for turning out the room light. It is obvious that this should not be connected to a white room light because turning the room light on and off while operating a fluoroscope would ruin dark adaptation. There are some installations in which the auxiliary switch operates a red room light. While it is often desirable to have a very dim red room light in the room to avoid stumbling over furniture, any red room light that is so bright that it must be extinguished during fluoroscopy obviously interferes to some extent with eye adaptation. The importance in keeping the total fluoroscopic dose rate low is so great that considerable attention to room darkening and eye adaptation facilities is justified. The age and relative sensitivity of the fluorescent screen should not be overlooked.

Having thus disposed of the checking of the protection afforded to the operators and technicians of the equipment, let us consider the patient. First of all let us keep reminding ourselves of a few facts:

(1) There is no evidence that the extent to which radiology is practiced today need be reduced if certain long-established safeguards are employed.

(2) Except for a few rare and drastic life-saving techniques, such as cardiac catheterization and really critical pelvimetry, there is no reason to believe that any individual patient will be exposed to an extent that even a statistical increase in chances of incurring any of the well known radiation effects could be demonstrated, *if* the examination is properly made.

(3) The principal reason for concern for the exposure of individuals and also the reason for recent reduction in permissible dose to individual members of the general population (those not in the category of radiation worker) was for long range genetic considerations. The principal reason for the efforts being made today to reduce the exposure of medical and dental patients is not primarily for their own safety but rather for the preservation of the race.

Some thought should also be given to the exposure of neighbors. The drastic 1957 thirtyfold reduction in permissible exposure to those not classified as radiation workers was accompanied by a five-year grace period for conversion to the new standard. We have found evidence that there has been considerable procrastination by operators of x-ray installations, probably because the five-year period of grace appeared to be so long. The fact is that well over four of the five years have already passed and it is likely that shielding designed according to the old standards will have to be augmented in order to protect next-door neighbors from excessive radiation exposure.

Radioactive Isotopes

The use of radioactive isotopes may be generally divided into two distinct classes. One is the case in which the radioactive material is employed as a source of penetrating gamma

radiation. This is most commonly employed either in medical teletherapy or industrial radiography. Such applications may be treated very much the same as an x-ray installation, except for the problems of storing and transportation. Experience has shown that there is little likelihood of overexposure from these sources, except through gross ignorance as to the simple safety precautions necessary in handling or through accident or loss.

The other class of use is that in which loose materials are used, either as tracers in medicine and in industry or where certain materials are administered to patients for radiation therapy. Because of the very conservative working standards established by the Atomic Energy Commission as a condition of licensing for such materials, the large majority of users are well trained and have developed good work habits. The very few overexposures which have been reported proved not to be very serious in nature and constituted what might be considered an acceptable risk considering the large numbers of users at the present time.

In general, compared to x-ray installations, the use of radioactive isotopes does not appear at present to be a very serious radiation control problem.

Radiation Accidents

This phase of the radiation control program consists largely of planning standard procedures, particularly in storage and transportation of radioactive materials and also in planning programs of action in the event of accident. The latter phase usually should include a cooperative plan with police and fire departments as well as any other government agencies whose talents might be utilized. Since this subject has been presented in a separate report by another member of our staff (this Journal *22:* 130, April, 1961), it is not necessary to go into details here.

Reactors

The location of a reactor, particularly one for producing power, is an important phase of radiation control that in itself has many ramifications. Although there have been several reactor accidents which have been considered serious, even these have not resulted in any injuries or contamination to the extent that the general public has been affected. There have been accidents in experimental reactors but that subject is considered beyond the scope of this report.

Shipping

As the shipping of radioactive materials increases, particularly when the return of spent fuel to chemical processing plants increases significantly, care must be exercised in its storage and transportation. The Atomic Energy Commission has kept a careful record of all transportation accidents to date and although there have been a number which have been considered serious, there is no record of any injuries or overexposures resulting from them. At present, one of the principal objectives of a transportation control program is to prevent public hysteria which is apt to follow exaggerated news reports such as those which have followed transportation accidents of this type in the past. A system of alerting qualified experts quickly is probably the most effective means of control in this field. We have made plans to route particularly large shipments in such a way as to avoid highly congested streets in New York City and also to avoid times of day when traffic is heavy. Considering the manner in which most such materials are packaged, there is little likelihood that serious radiation injuries could result. It is possible that contamination problems might be serious, but a well developed plan of action could control a contaminated area until adequate cleanup is completed.

Fires, Explosions, etc.

For several years both the Fire Department and the Police Department of New York City were concerned with the possibility of radiation exposure and contamination of police and fire personnel and others in the event of a fire or accident involving radioactive materials. The Fire Department had over 500 locations designated for special attention because of the presence of radioactive materials. A review of these locations indicated that most of them involved trivial amounts of material that were not likely to result in significant exposures even under the worst conditions.

A study was instituted in order to characterize the various types and quanities of radioactive materials in terms of their hazard under unusual conditions of fire and accident. In this study we were assisted by physicians who had clinical experience in the application of radioactive isotopes. The details of the study are too extensive to cover in this presentation and, in fact, are being prepared as a separate study. The conclusion was, however, that any radioactive material in a quantity less than one-million times that which is the criterion for exempting it from licensing and registering is not

likely to present a significant hazard in the event of a fire or accident.

By applying this criterion we were able to reduce the number of locations requiring special attention, from over 500 to less than 50. It is believed that this evaluation is quite conservative and that further study will permit a further reduction in the number of locations which we designate as "critical radiation locations."

Waste Disposal

It is believed that the waste disposal criteria established by the Atomic Energy Commission for its licensees are quite conservative and there is little likelihood of significant contamination of either ground waters, soil or air in the immediate future. We are, however, accumulating data on actual methods of disposal in order to establish long-range policies. It is believed that since the contamination of the environment with radioactive materials, particularly long-lived ones is irreversible. Any radioactive waste disposal policy must be a very conservative one. The present New York City Health Code provides that no one may dispose of radioactive wastes in any manner without prior approval of the Commissioner of Health. At present, we have given blanket authorization for every user to dispose of radioactive wastes in the manner provided for in his AEC license unless, after review, such approval is either rescinded or modified. The few radium users not under AEC jurisdiction are being reviewed individually.

Conclusions

Considering the fact that there are over 13,000 sources of radiation in New York City and that there are, at present, hundreds of recommendations applicable to most of these sources, our control program must concern itself only with those matters which constitute the greatest potential hazard to users and to the general public. We believe that our present program does this with a minimum of effort.

Recommendations Regarding Respiratory Protection Against Highly Toxic Aerosols

THE JOINT AIHA-ACGIH COMMITTEE on Respiratory Protective Devices after considering the current problems of protection against highly toxic aerosols has issued this statemet regarding respiratory protection for these situations. The U.S. Bureau of Mines is carrying out a program which will eventually lead to the preparation of performance requirements for respiratory protective equipment designed to protect a wearer against the inhalation of highly toxic aerosols. The Joint AIHA-ACGIH Committee believes that some performance criteria are necessary to cover the interim before the advent of formal approval procedures. In their recommendation the Committe has defined terms as follows: (a) Highly toxic aerosols are defined as solid or liquid particles of materials which are significantly more toxic than lead but which present no inhalation hazard due to vapors of the materials at temperatures less than 100°F. (b) The term "known concentration" as used in this statement implies a knowledge of the concentration based on actual measurements prior to exposure, sufficient previous evaluation of the operation, or the careful evaluation of the operation and a conservative estimate of the concentration by a trained observer.

For the interim, the Joint Committee recommends the following approach to the protection of personnel against the inhalation of highly toxic aerosols:

A. Highly Toxic Aerosols of Unknown Concentration

Use respirators that provide a positive pressure at all times in the breathing zone of the wearer. Such respirators include certain types of supplied-air respirators and self-contained breathing apparatus.

B. Highly Toxic Aerosols in Known Concentration

For exposures to concentrations that are less than 100 times the threshold limit value, use a full facepiece with "high efficiency" filter.

The wearers should be instructed in the proper method of fitting and using the respiratory protective equipment, and the equipment should be maintained in good operating condition.

Design Features and Operational Procedures for the New Brookhaven National Laboratory Radiation Laundry and Reclamation Facility

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The decontamination, reclamation, or disposal of radioactively contaminated tools, equipment and clothing presents many varied and non-routine problems. The Brookhaven National Laboratory facilities and procedures for these operations are described. For safety and economy these operations are grouped in a facility with specially designed ventilation and controls under the supervision of a Health Physicist.

IN most laboratories which handle radioactive materials, the question arises as to the economic feasibility of reclaiming contaminated tools, equipment and clothing. At the same time, many small jobs occur which involve levels of radiation sufficiently high to justify the use of a hot laboratory facility but, because of their brief duration and non-routine and varied nature, the expense of setting up such a facility is prohibitive.

These problems did arise at Brookhaven several years ago, at which time it became obvious that the make-shift and temporary facilities then in existance would have to be replaced by something more adequate as the need increased. The knowledge gained from several years experience plus an inspection trip made to other AEC sites helped with the design of a facility which was suited to the local needs. The facility has now been in operation for about two years.

For reasons of economy, and because of the close relationship between the two functions, it was decided that laundry and reclamation should be carried out in one building rather than in separate facilities. This plan eliminated the duplication of utilities, locker rooms, sanitary facilities, etc., but, at the same time, it brought under one roof operations involving high radiation levels and work where the levels are quite low or insignificant.

Reclamation Facility

The reclamation or decontamination facility, located in one-half of the building, consists of a room of about 2400 square feet floor space on grade with two large roll-up doors on adjacent sides to permit entry of trucks and trailers. A bridge crane permits the handling of heavy equipment and the erection of temporary shields at any place within the room with a minimum of effort. There are few permanent installations on the floor, which leaves most of the area available for use.

The facility is used for the decontamination of any object which is considered to be worth the expense involved to reclaim it. Decontamination may be by detergent, steam cleaning, grinding, etching with acid, or any other method which seems appropriate. Plans are in the advanced stage to construct a shot blasting room as a supplement to the existing building.

Inasmuch as the reclamation building is operated by the same men who operate the waste disposal area, many of the more difficult waste disposal operations are carried on in this room as time allows. The objective of this type of operation is to sufficiently reduce the waste material in size by acetylene cutting, sawing, or disassembly to allow packaging for disposal.

The Brookhaven Reactor, being primarily a research reactor, produces some unusual waste products. The normal piece of experimental equipment which has been in the reactor consists of one or more leads, cables or tubes, at the end of which is the container for the experimental equipment. Inasmuch as some of this equipment has been in a neutron flux in excess of 10^{13} neutrons per square cm per second for as long as a year, the radiation levels upon removal are high. However, in spite of this, re-

Work performed under the auspices of the U. S. Atomic Energy Commission.

covery of foils or some other part of the equipment quite often is essential to the success of the experiment. At the same time, because Brookhaven uses concrete vaults for disposal of its wastes, compact packaging is necessary and the experimenter is encouraged to cut up and compact his experimental waste for disposal when finished with his experiment. The reclamation room is used for this work and is thus used somewhat as a semi-hot laboratory. Since no two disassemblies are alike, no permanent installation has been set up for the work. Rather, shielding blocks of high density concrete are piled up with the crane to suit the needs of the experimenter. A leaded glass window can be placed at any location in the shielding wall so as to allow the worker to see what he is doing. (Figure 1.)

These dismantling jobs, as well as some of the high level decontamination work, have the inherent danger of producing high levels of airborne radioactivity. It is important that proper ventilation be provided to insure that any activity produced is not spread throughout this room or to other parts of the building. To provide ventilation, two 6000-cfm blowers are located on the roof at diagonal corners of the room. These provide for exhaust at the ceiling or at floor level by the use of sections of 12-inch diameter flexible tubing, commonly called "elephant trunks". These tubes are long enough so that one or the other will reach to any part of the floor area. These flexible ducts are placed at or near floor level for disassembly work or shorter lengths may be used if bench work is to be done. They have proven to be quite effective in preventing the spread of airborne contamination away from the immediate area of an operation. All ventilation in this room exhausts to the outside through absolute filters.

A standard fume hood is tied in with one of the ventilation fans. It can be operated separately but not at the same time as the other system mentioned above. This hood is used for more refined work such as the decontamination of small parts or the preparation of water samples.

The basic source of heat in this room is from radiant floor panels. This type heating system was installed to provide the lowest air velocities possible under normal operating conditions, but it has the disadvantage of not having a fast recovery in the event of a large heat loss such as is experienced when the ventilation system is in operation or the large roll-up doors are opened. To replace this loss of 12,000 cfm, tempered makeup air is introduced by four 2000-cfm fresh-air unit heaters located high on the side

FIGURE 1. A shielding wall of high density concrete blocks being assembled with a leaded glass insert.

walls. This 8000 cfm of makeup air tends to keep the room under slight negative pressure while "hot" operations are going on and at the same time prevent excessive chilling.

Because of the height of the unit heaters, a minimum of air movement is experienced at the floor level. With the supply at the top and exhaust at the bottom, the tendency is for airborne contamination to stay at or near floor level. One significant exception to this has been found when acetylene cutting is done. Upward convection currents caused by high temperatures cannot be overcome by the air flow in the flexible tubing. Under these conditions, collection of this smoke and contaminated air is done at the ceiling.

The floor of this room takes considerable abuse from the movement of heavy equipment and also from the chemicals and steam used in decontamination. With this in mind, it was necessary to find a floor covering which was not only extremely durable and which would not chip, but one which was chemically inert. After testing many different materials, an epoxy resin floor surfacing material mixed with a fine silica aggregate was chosen. This floor material has the advantage of being extremely hard and smooth after curing and it can be molded smoothly to continue up the side walls to any desired height. This advantage eliminates a possible crack at the intersection of the side walls and the floor, which could cause a build-up of radioactivity. After two years of hard service, there is no evidence of gouging or scratching. Slag from acetylene cutting will melt the surface, but repairs are quick and easy and restore the floor to its original condition.

Because of the large amount of water used in decontamination and in clean-up, it was necessary to install a liquid waste collection and hold-up system for this room. Since most wet decontamination involves acids, this system was made of stainless steel throughout. Four floor drains and two sinks feed into four-inch drain lines leading to two 2000-gallon stainless steel storage tanks located underground far enough away from the building to allow for easy excavation in the event of breakdown. After being sampled and assayed, waste liquid can be pumped to the sewer if the contamination levels are low enough or hauled off by truck to storage and evaporation if the levels are high.

Entrance and exit from this room is accomplished via an airlock to which only one door may be opened at a time. This airlock is pressurized higher than the surrounding rooms to prevent air movement from the reclamation room to the rest of the building. This is accomplished by a small independent blower which, if inoperative, shuts down all other ventilation outside of the reclamation room. The building was so designed that, in the event of a major incident causing high levels of radioactivity in the decontamination room, spread to other parts of the building could be controlled, both by the routine use of the airlock and by the use of an emergency switch near the entrance door which shuts off ventilating air throughout all other areas of the building.

Procedures require that when personnel working in the reclamation room know that their clothes are contaminated, they will remove their outer garments before entering the airlock. Under normal conditions, however, they enter a change room via the airlock and leave their protective clothing here in hampers. From here they must pass through a shower room before entering the locker area.

Radiation Laundry Procedures

It is very desirable to launder protective garments together that are similarly contaminated with approximately the same amount of radioactive material. At Brookhaven the contaminated laundry is separated in two ways. The first method is by areas of use which keeps garments used in areas where tracer work is being done separate from those used in higher level radiation areas. Monitoring of these garments is done at the area of use under the direction of the Health Physicist in charge of the area. Any garment which is sufficiently contaminated prior to washing to be detected on a Geiger counter instrument is separated from the other garments and is replaced with a new item from stock. This contaminated garment is then added to the stock of garments in use in higher level radiation areas.

Protective clothing from the high level areas is brought to the sorting room at the laundry to be monitored. Here it is arbitrarily sorted into two groups of either over or under two mrad/hr beta-gamma, as shown by standard GM survey instruments. Garments which have been checked at under two mrad/hr, and those which originated in the low level areas, are washed separately in one large machine so as to minimize cross contamination. Those garments which have been checked with higher levels are washed, extracted, and dried in machines in the same room which are used exclusively for this purpose. These garments are rechecked after washing to see if they are clean enough for reuse. Potentially contaminated garments from the research hospital which normally present no radiation problems are laundered in an adjoining room in other machines.

Radiation Laundry Facility

Within the laundry half of the building (Figure 2) there are some areas which present greater potential hazards than do others. Of these, the sorting room presents the maximum possible hazard, and it is thus established as second only to the reclamation room in the hazard sequence for the building. This small room is supplied with 400 cfm of fresh air and is exhausted at 300 cfm through each of two exhaust ducts, thus producing slightly negative pressure and preventing spread of any possible airborne contamination from the room. If the Health Physicist feels that the work being done is particularly hazardous, he may shut down all ventilation to this room and all other areas of the building with the exception of the airlock by means of a wall switch.

Further down in the airborne hazard sequence is the washing room where clothes are loaded into the washing machines. Here again, a wall switch enables the operator to shut off ventilation to those areas of less hazard, if the necessity arises. In the washing room, a total of 2000 cfm is provided by four ceiling fans and 2600 cfm is withdrawn by floor exhausts.

The same technique of ventilation is followed throughout the laundry areas where airborne contamination is possible. This solves two problems at once. First by withdrawing air from near floor level, air movement upward is kept at a minimum. Thus, "fallout" from airborne contamination is localized on the floor near the exit ducts, which is easily mopped, and the health hazard is minimized by preventing particulates from rising to the breathing zone for more than short periods. Air from these more contaminated areas is exhausted out of doors and never recirculated. Secondly, in each case slight negative presure is produced in the radiation work area which causes air to flow into these areas from surrounding cleaner areas. Figure 2 shows that the laundry return corridor and the pressing room are oversupplied to make up the shortages in the radiation work areas mentioned above. Air flow is thus assured from clean areas to areas of potential contamination.

In the sink room filter respirators are checked, cleaned and disinfected. This is the one room of the entire building which requires the most meticulous standards of cleanliness in order that the lowest levels of contamination may be detected. Face pieces and filters must be separately checked for both alpha and beta-gamma contamination. Face pieces are rather easily decontaminated, but filters which show any evidence of contamination are discarded. Those filters showing no radioactivity are dipped in a disinfecting solution and then dried for reuse. Experience and retesting have shown that, if the

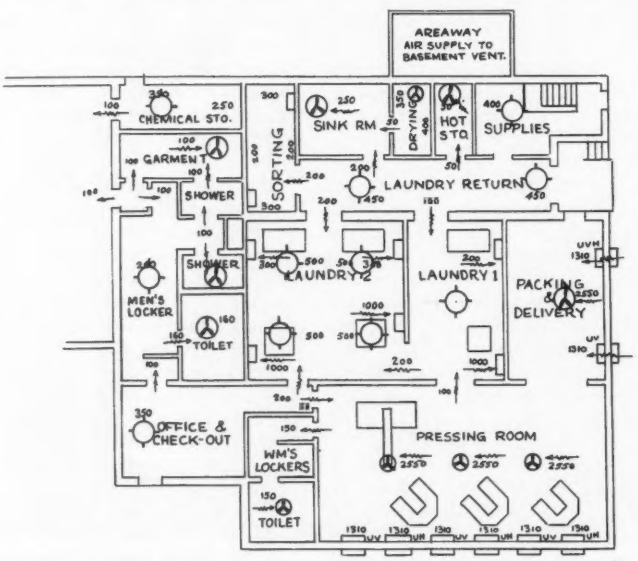

FIGURE 2. Layout of laundry and change facilities at reclamation and laundry facility. Ventilation is indicated by arrows and flow rate values.

respirator filters are carefully handled, they can be disinfected as many as five times without showing and appreciable loss of filtering efficiency. The reuse of these filters represents a considerable saving to the Laboratory.

Before the construction of the new laundry building, the Laboratory had had several years of operating experience with a temporary facility. Here the contaminated liquid waste from the washing machines was held up in 2000-gallon tanks and assayed daily, or sometimes more frequently. It was found that even in periods of peak activity, the quantity of activity found in this wash water was not sufficient to necessitate special treatment. Thus, when the new facility was constructed, all laundry wastes were piped directly to the sanitary sewer. At the same time, however, it was recognized that future growth or regulations might alter requirements, so a shut-off valve and a tee were installed in the lines at the point nearest the hold-up system for the reclamation room. Thus, water can be diverted to the hold-up tanks with only minor plumbing changes if it becomes necessary.

During the period that the old laundry facility was in use, it was determined that lint from a dryer effluent posed an airborne contamination problem. Air samples taken from the effluent showed considerable radioactivity and lint collected in the machine produced surprisingly high concentrations of radioactivity. In the new laundry facility this problem was easily solved by the installation in the duct of a simple, yet effective lint catcher made of a standard galvanized waste can with a burlap bag liner. This can and bag combination has proven to be cheap and efficient and has eliminated the problem of radioactive lint being exhausted to the atmosphere.

Summary

The actual operation of the laundry is handled by personnel from the Plant Maintenance Division. Health Physics personnel handle all monitoring operations and perform all reclamation work in connection with respiratory equipment. Laundry procedures and wash cycles are, in general, worked out by Health Physics supervision. All work in the reclamation half of the building is under the direct supervision of Health Physics and is usually done by Waste and Reclamation Technicians of the Health Physics Division. The extensive experience of these people makes it possible to use many short cuts in performing routine laundry and reclamation work. The procedures and techniques used are simple, yet the two years of operating experience have shown them to be safe and effective. Persons not trained in radiation protection methods would undoubtedly require more elaborate procedures, precautions and facilities.

Hydrogen Sulfide Fatality in a Poultry Feather Fertilizer Plant

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A workman attempting to repair a ruptured outfall line from a poultry feather cooker was found dead. A subsequent autopsy and investigation indicated that death was caused by the inhalation of hydrogen sulfide produced in the cooking cycle and discharged through the outfall pipe during the pre-drying cycle.

Introduction

HYDROGEN sufide is important to industry because of its nuisance value more often than its usefulness. It is a product of the putrefactive process and it is also evolved as a waste product in a variety of manufacturing and technical processes involving chemical reactions. It is always found where vegetable or animal matter is undergoing decay as in sewers, sewage treatment plants, tanneries, fur dressing and felt making establishments, abattoirs, beet sugar factories and breweries. Hydrogen sulfide is emitted as a waste product in the manufacture of viscose rayons, in the manufacture of various dyes, and in the vulcanization of rubber. Industrial exposures may also be encountered in petroleum refining, in chemical laboratories, and in mines as well as in the gas and coal industry.

Toxicology

Hydrogen sulfide, even in small concentrations, is destructive to most forms of life. It is a dangerously poisonous material, highly flammable, and irritating to the eyes and respiratory tract. It can cause subacute flashes of light, contracting of the pupil of the eye, sharp pains, photophobia, and ulceration of the cornea. In the presence of oxygen it can form explosive mixtures. Increasing concentrations become more and more harmful; a high enough concentration can result in instant death. Exposure to 1,000 parts per million and over is rapidly fatal.[1]

Hydrogen sulfide has a characteristic and offensive odor of rotten eggs although its odor in higher concentrations has been described as sweetish. Even in low concentrations the odor of hydrogen sulfide is easily discernible, but this is only true when it is first encountered. It is not a reliable warning signal since high concentrations have a paralyzing effect on the olfactory nerves. Low concentrations, upon prolonged or repeated exposures, tends to "tire" the sense of smell to a point where exposed personnel may fail to detect its presence.[2]

Subacute exposures are characterized by marked conjunctivitis and respiratory tract irritation. It has been postulated that the irritant action is due to the combination of the hydrogen sulfide with the alkali present in the moist surface tissues forming sodium sulfide—a caustic.[3] The usual symptom of acute poisoning is unconsciousness within a few seconds, coming on without pain or significant warning. As a rule, unconsciousness is followed immediately by cessation of respiration. The heart continues to beat for five to ten minutes during which rescue may be effected and artificial respiration given, otherwise death will follow. The gas is readily absorbed into the blood stream resulting in systemic poisoning along with paralysis of the respiratory center of the brain.[4] Death results from asphyxiation. Hunter states, "A worker upon inhaling a large dose of the gas falls as if struck by a blow and dies almost instantaneously."[5]

Case History

The plant, in which this fatality occurred, processed poultry feathers into fertilizer. After the baled raw materials were received, they were placed in a steam cooker, to which limestone was added in order to soften the quills. Upon completion of the cooking cycle, steam and liquids were aspirated from the boiler through a four-inch pipe which discharged into a nearby sawmill log pond. Following the pre-drying operation, the "cook" was dried in a rotary kiln, then ground and finally bagged.

On the day in question, at approximately 12:45 pm, the deceased walked out of the door

of the plant with a rag and screwdriver in his hand. He was walking toward the sawmill log pond located in some high reeds approximately 200 feet from the building. When he did not return after 15 or 20 minutes, one of his fellow workers and a truck driver entered the pond area to investigate, and discovered the deceased draped over the cooker outfall line. A few days previous, the deceased had mentioned that employees of a nearby veneer plant had complained of obnoxious odors, and upon close scrutiny had discovered a hole in the pipe. His obvious intentions were to stuff the rag into the breach thereby preventing the escape of waste gases.

The next day an autopsy was performed at the request of the county coroner. Significant findings from this report follows:

Anatomical Diagnosis

1. Bilateral marked hemorrhagic pulmonary edema.
2. Dusky cyanotic color of brain and skin of head.
3. Evidence of increased intracranial and cerebral edema, cause undetermined.

Microscopic

1. Lungs—the alveolar spaces were filled with edema fluid and contained numerous pigment-filled macrophages. The vascular elements were not particularly congested. Diagnosis: Pulmonary edema.
2. Sections of the other representative tissues, including the brain showed no histological lesions.

Cause of Death

The cause of death was apparently from hydrogen sulfide inhalation. Chemical tests were needed to provide the necessary proof. The dusky color of the head and neck noted by the embalmer and the brain noted at autopsy is apparently consistent with the bluish-green color noted on occasion in the tissues due to degeneration of the blood containing sulfmethemoglobin. The fact that the blood had been washed out by the embalmer would seem to indicate the reason this discoloration was not widespread throughout the body at the time of the autopsy.

Comment

In order to prove the above a sample of blood was sent to the State Toxicology Laboratory to be examined for sulfmethemoglobin. In a rapidly fatal case of hydrogen sulfide poisoning, sulfmethemoglobin may be difficult to demonstrate since the pigment forms rather slowly.

The results of laboratory examination of the blood indicated that the qualitative determination for hydrogen sulfide was positive by distillation and by vapor chromatography. Sulfmethemoglobin was inconclusive.

Plant Survey

A week after the above fatality, a survey was made of the plant to determine hydrogen sulfide concentrations, particularly during the cooker

TABLE I

Hydrogen Sulfide Concentrations at Various Locations in the Fertilizer Plant

Sample No.	Location	H_2S[1] ppm	Remarks
1	Leak in cooker	200	
2	Hopper	0	
3	Loading platform (cooker)	Trace	
4	General plant atmosphere	0	
5	Above hopper	0	
6	Hole in outfall line (1st "cook")[2]	2000	First vapors to appear
7	Hole in outfall line (1st "cook")[2]	3000	5 minutes after vapors appeared
8	Hole in outfall line (1st "cook")[2]	80	10 minutes after vapors appeared
9	Hole in outfall line (2nd "cook")	2000	First vapors to appear
10	Hole in outfall line (2nd "cook")	4000	3 minutes after vapors appeared
11	Hole in outfall line (2nd "cook")	70	10 minutes after vapors appeared

[1] Samples collected and analyzed with MSA Hydrogen Sulfide Detector.

[2] Samples taken approximately 2 feet above pipe.

FIGURE 1. Location of leak in cooker outfall line (body found draped over pipe).

predrying cycle. It was learned that two "cooks" are processed each day, and that the predrying operation endures for approximately 15 minutes after a "cook".

The results of this survey (Table I) indicated that in the area of the ruptured outfall line (Figure 1) hydrogen sulfide ranged from concentrations of at least 2,000 parts per million at the start of the predrying cycle to 3,000 to 4,000 ppm three to five minutes after the start of the cycle. Ten minutes later relatively harmless amounts of hydrogen sulfide were encountered.

Upon entering the plant proper, a leak was noted in the cooker. A sample taken in the flow from this leak indicated a hydrogen sulfide concentration of 200 ppm. No other operation appeared to produce this gas.

Conclusions

The deceased, in attempting to repair a leak in the cooker discharge line, was apparently overcome by the vapors containing hydrogen sulfide. The hole was located in the side of the pipe, and in such terrain, making it necessary for an individual attempting to repair the leak to assume a position with his face close to the opening. Consequently, his breathing zone would be in the direct path of the waste vapors before they had an opportunity to be diluted. The vapor appeared, he inhaled, became unconscious, and a few minutes later—death.

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